ECOLOGY OF JUVENILE PINK SALMON IN THE NORTH GULF OF ALASKA AND PRINCE WILLIAM SOUND

A

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By

Jennifer Lynn Boldt, B.Sc., M.S.

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Bell & Howell Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

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By

Jennifer Lynn Boldt

RECOMMENDED:

Kenneth O. Coyle

Thomas Weingartner

[illegible]

Terri Haldorson
Advisory Committee Chair

W W Smoker
Director, Fisheries Division

APPROVED:

[illegible]
Dean, School of Fisheries and Ocean Sciences

[illegible] Kan
Dean of Graduate School

12-5-01
Date

Abstract

Increased production of salmon in Alaska has been accompanied by a decrease in average body size and decreased wild stocks, indicating a possible density-dependent response to increases in salmon populations and hatchery releases. Pink salmon have a short two-year life cycle and most post-hatch mortality is thought to occur during their first months at sea; therefore, processes in the early marine residence period may determine abundance. Geographic and seasonal patterns in distribution, growth, and condition of juvenile pink salmon during their first months at sea were examined in Chapter 1. The migration of pink salmon from Prince William Sound (PWS) occurred over several months. Fish lengths, weights, and energy contents varied geographically and seasonally. Pink salmon energy content was highest on the Gulf of Alaska (GOA) shelf in July and August and lowest in PWS in July, indicating that growth conditions were better on the GOA shelf. Spatial and temporal variation in growth and condition is indicative of disparate feeding opportunities for juvenile pink salmon. An unusual aspect of this study was the concurrent collection of zooplankton and fish in PWS and on the GOA shelf. Geographic and seasonal changes in juvenile pink salmon diets were examined during their first six months at sea in Chapter 2. Pink salmon diets varied geographically and seasonally, and prey size increased as fish grew. A unique opportunity existed to compare the energy content of thermally marked hatchery pink salmon to their wild counterparts in PWS (Chapter 3). Fish condition varied geographically, however, there were no differences among hatchery groups and/or wild pink salmon at any one location. This indicates that fish were staying together as a

group. In Chapter 4, pink salmon consumption was estimated to represent a small fraction of the production but potentially a large proportion of the available standing stock of zooplankton in PWS. Geographic variations in fish condition, diet, and zooplankton densities were observed in this study. This supports the hypothesis that local processes, including food depletion and/or zooplankton availability are important to juvenile pink salmon.

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General Introduction

Pink salmon are an economically and ecologically important fish in the northeast Gulf of Alaska (GOA) and Prince William Sound (PWS). They provide the largest salmon fishery in Alaska and are prey to marine mammals, birds, and piscivorous fish (McNair 1997, Pitcher 1981 and 1980, Ainley and Sanger 1979). Pink salmon are also important planktivores in the GOA feeding primarily on zooplankton throughout their life cycle. Their short two-year life cycle and vital role in the North Pacific makes this species a good indicator of ecosystem production and health.

Historically North Pacific salmon have experienced oscillations in their populations that have been attributed to atmospheric and oceanic conditions (Beamish and Bouillon 1993, Coronado and Hilborn 1998, Mantua et al. 1997). Conditions changed in 1977 as indicated by a positive Pacific Decadal Oscillation (PDO) index (Mantua et al. 1997). This regime shift associated with the Aleutian Low may have changed the carrying capacity of northern Pacific ecosystems, resulting in high salmon production in Alaska concurrent with low salmon production in Oregon and Washington (Beamish et al. 1995). This increased production of salmon in Alaska has been accompanied by a decrease in average body size in 45 of 47 North Pacific salmon stocks, indicating a possible density-dependent response to the increase in salmon populations and hatchery releases (Bigler et al. 1996).

Salmon enhancement in PWS increased from the mid-1970's to 1989, and currently PWS hatcheries release about 600 million pink fry annually (McNair 1997). In PWS, the increase in pink salmon hatchery releases has been correlated to a decline in wild salmon runs. Wild salmon returns in PWS peaked in 1983 and declined until 1995 (Cooney and Brodeur 1998). Intraspecific competition and, hence, food-limitation may have occurred, as implied by a negative correlation between the number of pink salmon smolts and their survival (Peterman 1978). Concern over declining wild stocks and returning salmon body size has led to the hypothesis that the carrying capacity of PWS, and possibly the GOA, for salmon has been reached (Beamish et al. 1997, Cooney and Brodeur 1998).

The Global Ocean Ecosystem Dynamics program (GLOBEC) was developed to advance our understanding of the GOA ecosystem and the effects of climate change on distribution, abundance, and production of marine animals. A core GLOBEC hypothesis is that ocean survival of salmon is primarily determined when salmon are juveniles in coastal areas and is affected by interannual and interdecadal changes in physical forcing and by changes in the ecosystem food web dynamics. A rare chance was presented to view the 1998 year class of pink salmon at a variety of locations and times. To contribute to the understanding of the physical and biological factors that affect juvenile pink salmon, this dissertation describes the growth, condition, and feeding of this year class of juvenile pink salmon during their first months at sea. In Chapter 1, I describe the distribution, condition, and growth of one year class of juvenile pink salmon in Prince William Sound and the adjacent Gulf of Alaska shelf. In Chapter 2, I examine pink salmon diets during their first six months at sea, to determine if diet varies among areas and seasons. An unusual aspect of this study was the concurrent collection of zooplankton and fish in PWS and on the GOA shelf. I examine the portion of the zooplankton community that pink salmon in PWS utilize. In Chapter 3, a unique opportunity existed to compare wild and thermally marked hatchery pink salmon size and condition in different areas of PWS. I relate differences in fish condition among areas to zooplankton density and water column structure. To address the issues of food limitation, in Chapter 4, I estimate the juvenile pink salmon consumption of zooplankton during their residence in PWS. This was accomplished with the use of a bioenergetics model which, unlike other studies examining fish consumption in PWS, applies fish mortality throughout the period examined, and incorporates physiological parameters to account for costs of metabolism, egestion, and excretion.

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Chapter 1

Distribution, growth, and condition of juvenile pink salmon in coastal waters of PWS and the northern Gulf of Alaska[1]

Abstract

Pink salmon have a short two-year life cycle and most marine mortality is thought to occur during their first months at sea; therefore, processes in the early marine residence period may affect abundance. A unique opportunity existed to examine the geographic and seasonal patterns in distribution, growth, and condition of the 1998 year class of juvenile pink salmon during their first months at sea. Samples of this year class were collected five times from the time of their release into Prince William Sound (PWS) in May to October in the Gulf of Alaska (GOA). PWS hatchery pink salmon were found approximately 350 km from PWS in August, yet some were still found on the shelf, approximately 90 km from PWS, in October. This protracted migration of pink salmon from PWS may have been related to hatchery or spawning river location and/or varying growth conditions in PWS. Fish lengths, weights, and energy contents varied geographically and seasonally. Pink salmon in PWS grew at an estimated rate of approximately 3.6 to 6.7% body weight per day. In August, growth rates were similar to those estimated for fish sampled in July (3.6-5.6% body weight per day). The mean energy content of juvenile pink salmon upon release from hatcheries ranged from 4,975

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to 5,542 cal/g dry weight. In July, fish on the GOA shelf had a higher energy content (4,845 cal/g dry weight) than those in PWS (4,370-4,780 cal/g dry weight). Fish on the GOA shelf maintained a high energy content in August (4,757-4,914 cal/g dry weight). Mean energy content decreased slightly in October, with values ranging from 4,662 to 4,794 cal/g dry weight. PWS hatchery pink salmon cohorts also had higher energy content in July and August on the GOA shelf than fish in July in PWS. Spatial and temporal variation in fish condition is indicative of variable feeding and growth conditions. The high energy content of fish on the GOA shelf in July and August indicates that growth conditions were better on the GOA shelf than in PWS.

Introduction

Pink salmon are an economically and ecologically important fish in the northeast Gulf of Alaska (GOA). They provide the largest salmon fishery in Alaska and are prey to marine mammals, birds, and piscivorous fish (Ainley and Sanger 1979; Pitcher 1981, 1980; McNair 1997). Pink salmon are also important planktivores in the GOA feeding primarily on zooplankton throughout their life cycle. Their short two-year life cycle and vital role in the North Pacific makes this species a good indicator of ecosystem production and health. If fish experience good feeding conditions, they will be able to grow faster, and they will be able to store energy, thereby, improving their condition. Fish that exhibit high growth rates and are in good condition are, therefore, indicators of a productive and healthy ecosystem.

The highest mortality of pink salmon is hypothesized to occur in coastal areas during their first few months at sea as juveniles (Parker 1966); however, not much is known about the growth or mortality of juvenile pink salmon during early marine residence. Marine mortality of pink salmon from central British Columbia was found to be extremely high for the first 40 days at sea and then tapered off in subsequent days (Parker 1966). Chum salmon from southern British Columbia also experience high size selective mortality during early ocean residence (Healey 1982). Fish that are able to grow faster may be able to escape size-selective mortality; therefore, the physical and biological conditions juvenile pink salmon encounter may determine their survival.

Pink salmon fry from Prince William Sound (PWS) enter saltwater in April and May and remain in PWS for approximately four months (Cooney et al. 1978). They gradually migrate into deeper waters, leave PWS through southwest passages, and move westward over the continental shelf of the GOA. PWS hatchery pink salmon have been found approximately 750 km west of PWS near Mitrofania Island in August, 1996 (Farley and Munk 1997). In the following spring, maturing pink salmon begin migrating back to their natal streams.

The general circulation of the GOA is defined by the cyclonic Alaska gyre, which is dominated by the Aleutian Low (Niebauer et al. 1981; Mann and Lazier 1991). The northern part of the gyre consists of the fast, westward flowing Alaska Stream, which is concentrated along the shelf break in the upper 150 m (Royer 1980; Musgrave 1992). A front separates shelf waters from coastal waters (Johnson et al. 1988). Nearshore (within 50 km of shore) there is also the Alaska coastal current (ACC) or coastal jet, which is a fast and narrow (5-10 km wide) current that flows westward and is responsible for most of the transport in the Northern GOA (Royer 1980, 1982). The baroclinic flow of the ACC ranges from 15 to 100 cm/s and is controlled primarily by freshwater discharge and secondarily by wind stress (Royer 1980, 1982; Johnson et al. 1988). Peak flows of the ACC occur in the fall, at the time of maximum freshwater discharge. Part of the ACC flows into Prince William Sound (PWS) which contributes more freshwater to that part of the current (Royer 1980). Water from the ACC enters PWS through Hinchenbrook Entrance, after which it flows east to west and exits through Montague St (Niebauer et al. 1994). Some of the ACC water gets involved in the cylonic circulation in Northern PWS and therefore has a longer residence time (Niebauer et al. 1994).

During their migration through the ocean, pink salmon may encounter varying currents, temperatures, and feeding conditions that are important determinants of fish growth and survival. In the past, it has been difficult to follow the growth and condition of a single cohort of salmon from a specific geographical location. Currently, Prince William Sound (PWS) hatcheries thermally mark all hatchery pink salmon, enabling researchers to recognize these fish when captured anywhere in the ocean by examining their otoliths. This has made it possible to follow a single cohort of fish through its life at sea.

The goal of this study was to examine the life history of pink salmon during their first months at sea, as illustrated by the 1997 brood year, with the primary objective to identify periods and areas where growth or condition was enhanced or depressed. Additionally, growth of PWS hatchery fish cohorts was followed through the first three months of their life at sea. To accomplish these objectives I examined the distribution, timing, and movement of juvenile pink salmon through Prince William Sound and the adjacent Gulf of Alaska shelf and I examined the lengths, weights, and condition of pink salmon during their first six months of ocean residence.

Methods and Materials

Study Areas and Sampling Methods

The 1997 brood year of pink salmon was sampled opportunistically on five occasions in 1998 (Table 1.1): (1) In May hatchery fry were collected at release, (2) in the northeast GOA in July, (3) in mid-July in PWS, (4) in the northeast GOA in early

August, (5) in the northeast GOA in October. A variety of nets were used (Table 1.1); therefore, data analyses were performed only within, not across, sampling periods.

Hatchery Releases, May 1998

Pink salmon fry were collected from Prince William Sound Aquaculture hatcheries within PWS at the time of release (Figure 1.1, Table 1.2). Samples from Cannery Creek Hatchery (CCH) were collected from the early (May 7) and late (May 29) release groups. Two samples were also collected from Armin Koernig Hatchery (AFK), one early (May 8) and one late (May 24). One sample was collected from the Wally Noerenberg Hatchery early release group (May 1). All samples were frozen for later laboratory analyses.

Gulf of Alaska, July 1998

The Global Ocean Ecosystem Dynamics project (GLOBEC) conducted a fish sampling survey in the NE GOA along the Seward hydrographic line July 10-15, 1998 (Figure 1.1). A small number of pink salmon were collected on this cruise during daylight hours. These fish were sampled within 32 km of shore with variable-meshed gillnets. Gillnets used were 200 m in length, 3 m deep, and were comprised of four 50 m panels. The four panels had mesh sizes of 19, 25, 32, 38 mm stretched mesh. Two gillnets were tied together and soaked for about 2-4 hours. All pink salmon collected were measured and frozen for later laboratory analysis (Tables 1.1 and 1.2).

Prince William Sound, July 1998

Sampling took place in Prince William Sound (PWS) from July 14 to 19, 1998. The Apex Predator Ecosystem Experiment (APEX) project was conducting a survey of fish abundance and distribution in three important marine bird foraging areas of PWS, and collected some juvenile pink salmon. The three areas were Port Gravina in northeast PWS, Naked Island in central PWS, and Whale Bay-Bainbridge Passage in southwest PWS (Figure 1.1). Eight stations in each area were selected in a systematically random fashion. Blind sets were completed at the predetermined stations during daylight hours with a purse seine (200 m long, 20 m deep, 25 mm stretched mesh).

Two stations from each area, where a large number of pink salmon were captured, were chosen for analyses. The two stations sampled in northeast PWS were in Port Gravina, one station was near Knowles Head (N1) and the other was near Red Head (N2) (Figure 1.1). Stations sampled in central PWS included one on the east side (C1) and one on the west side (C2) of Naked Island. In southwest PWS, one station sampled was in Whale Bay (S1) and the other in Bainbridge Passage (S2) (Figure 1.1). Pink salmon collected were measured and frozen for later laboratory analysis (Tables 1.1 and 1.2). When there was a large catch of salmon, 10-15 pink salmon were preserved in 10% buffered formalin for diet analyses.

Gulf of Alaska, August 1998

The fourth sampling period was conducted in the northern GOA August 1-3, 1998 by the Ocean Carrying Capacity project (OCC). Fish were collected with a surface trawl that was 198 m long and had 1.2 cm mesh lining in the codend. The mouth of the net was 25 m wide and 35 m deep. Samples were collected during daylight hours at five stations (Figure 1.1). Two stations were sampled off of Cape Puget, one nearshore (CP2) and one over the shelf (CP1). Another two stations were sampled off of Cape Douglas, CD1 and CD2. The fifth station was sampled nearshore off of Gore Point (GP). Fifty pink salmon were collected from each station and frozen for later laboratory analysis (Tables 1.1 and 1.2).

Gulf of Alaska, October 1998

The GLOBEC project conducted sampling along the Seward hydrographic line in the northern GOA from October 2-9, 1998. Fish were collected with the same variable mesh floating gillnets that were used on the Seward hydrographic line in July, 1998. Sampling was conducted at night and nets were soaked for approximately 2 to 3 hours at 10 stations (Gulf of Alaska, GAK, stations) along the transect (Figure 1.1, Tables 1.1 and 1.2). Fish sampled were identified, measured, and frozen for later laboratory analyses.

Lab Methods

Standard and fork lengths, wet and dry weights, and caloric content of pink salmon were determined in the laboratory. Fish were thawed, blotted dry, measured for fork and standard lengths, and weighed to the nearest 0.001 g. Otoliths were removed and stored in 10% alcohol for later analysis. The stomachs of frozen fish were extracted, weighed, their contents removed and fixed in 10% buffered formalin. The stomach was rinsed, blotted dry, weighed, and then returned to the body of the fish, which was weighed again.

Wet and Dry Weights

A sample of 10-50 fish from each station was dried. Fish were placed in a drying oven at 60° C until a stable weight was reached (approximately 48 hours). The fish were weighed when dry and stored in a dessicator in a freezer until caloric content could be analyzed. Fish that were taken from hatcheries at the time of their release were very small; therefore, stomach contents and otoliths were not removed and the fish were dried whole.

Otoliths

Otoliths from each fish were mounted onto an individually labeled microscope slide with thermoplastic cement. The cement was melted around the otoliths by placing the slide on a hot plate and then the slides were allowed to cool. One otolith was then sanded with water on progressively smaller-grained lapping film (#1200 silicon carbide paper, 9 micron aluminum oxide, 3 micron aluminum oxide) until the primordia were on the surface of the otolith. A compound microscope was used to examine the otolith and primordia under 10X and 40X power. Each otolith was examined for the presence of a thermal mark. If a thermal mark was found, the type of mark was identified. If the otolith was damaged, missing, or difficult to analyze, the other otolith from the fish was sanded and examined.

Thermal marks consist of a banding pattern created at hatcheries by changing the water temperature surrounding the salmon eggs and sometimes alevins. Wally Noerenberg hatchery (WNH) marked all 1997 brood year pink salmon eggs with a band of 8 evenly spaced rings and marked alevins of late released fish with an additional band of 3 evenly spaced rings (WNH +). The Solomon Gulch hatchery (SGH) marked the 1997 brood year with one band of 6 evenly spaced rings. The Armin F. Koernig (AFK) thermal mark consisted of one band of 4 rings in the pre-hatch area of the otolith. Early release fish had only this mark, whereas two late release groups were also marked as alevins. One late release group had an additional band of 3 rings (AFK +) and the other group had a band of 4 rings (AFK 2+). Cannery Creek hatchery (CCH) marked the 1997 brood year pink salmon eggs with two bands of 3 rings each. It was assumed that salmon without thermal marks in PWS were wild salmon; however in the GOA, some unmarked fish could originate from hatcheries elsewhere that did not mark their fish.

Bomb Calorimeter Methods

Where possible, ten fish from each station or release group were analyzed for their energy content. A systematic random sample of fish, sorted by size, was examined at each station. Fish were sorted according to lengths and a random number generator was used to pick a sample of 10 fish for calorimetry. A Parr 1261 Isoperibol Calorimeter was used to determine the caloric content of fish. Fish were ground thoroughly with a mortar and pestle or an electric grinder. Each fish, or a subsample of each homogenized fish, was pressed into a pellet of about 0.15 g using a pellet press. Pellets were weighed immediately after being pressed. Methods used for the calorimetry process were as stated in the Parr manual (1994). Sulfuric and nitric acids are formed when a sample is bombed. It was assumed that these were zero, since the error is minimal (Parr 1994). There also may be other forms of nitrogen in the sample that would produce different amounts of heat than N_2 and these were not accounted for. The fuse wire used was nickel alloy (No. 45C10) which has 1,400 cal/g or 2.3 cal/cm. The amount of fuse wire used during the bomb was measured and the calorimeter accounted for this when calculating the final caloric content of the sample. The formula used to determine the caloric content of a sample was:

$$H_c = \frac{W\Delta T - e_1 - e_2 - e_3}{m}$$

H_C = Heat of combustion (eg. Hc of Benzoic acid = 6,318 cal/g)

W = EE value= Energy equivalent of the bomb = the amount of energy required to raise the temperature of the calorimeter 1 °C,

ΔT = temperature change in °C,

e_1 = heat from burning N_2, as total Na_2CO_3 used (0.0709 N),

e_2 = heat from burning S, assume = 0,

e_3 = heat from burning wire (amount of wire used), and

m = sample mass (g).

Length-Weight and Dry Weight-Energy Content Regressions

Whole wet weights (W) of fish were log-transformed and then regressed against the log-transformed standard lengths (SL) of fish:

$\log(W) = b + m*\log(SL)$, where

W = whole wet weight (g)

m = slope of the regression line

SL = standard length (mm)

b = intercept of the regression line.

Energy content (EC) was also regressed against percent dry weight (PD) to test for a relationship between the two:

$EC = b + m(PD)$, where

EC = energy content (cal/g dry weight)

m = slope of the regression line

PD = percent dry weight b = intercept of the regression line.

Growth Estimation

Growth was estimated for PWS hatchery juvenile pink salmon from the time of their release to the times of their capture in July and from release to recapture in August. There were enough samples of CCH, SGH, and early release WNH fish to estimate their growth (Table 1.3). An exponential model was used as in Willette et al. (1994):

$$G = \frac{\ln(W_c) - \ln(W_r)}{t_c - t_r}, \text{ where}$$

G= estimated growth (% body weight per day)

W_c= average weight of fish at time of capture (g)

W_r= average weight of fish at time of release (g)

t_c= date of capture

t_r= date of release.

There were three release groups of CCH fish in 1998; however, the release groups did not have distinct thermal otolith marks. This was the case for SGH fish as well; therefore, a range of possible growth rates was calculated for CCH and SGH fish. It was assumed that all recaptured fish were from the early release groups to estimate the lowest possible growth rate. To estimate the highest possible growth rate, it was assumed that all recaptured fish were from the late release groups. Since I did not get samples from all hatchery release groups upon release, I used the mean weights at release from hatchery data. Growth rates were calculated for each of the stations and recapture dates where sufficient CCH, SGH, and early WNH fish were sampled.

Data Analysis

Analysis of variance (ANOVA) was used to test for differences in lengths, weights, and energy content of pink salmon among stations within each sampling period. Data analyses were only conducted on data sampled within each sampling period, not across sampling periods. For example, an ANOVA was utilized to determine if the mean standard lengths of fish were significantly different among the five stations sampled in August in the GOA. Similar tests were conducted on data collected in July in PWS, in July in the GOA, and in October in the GOA. A single factor ANOVA was utilized, with station as the factor. Normal probability plots were used to test for normality and histograms and box plots were used to test for normality, outliers, and homoscedasticity of the data. If a significant difference occurred among stations or hatchery groups, *a posteriori* comparisons were made with Tukey's (for equal sample sizes) and Scheffe's test (for unequal sample sizes) (Zar 1974). The statistical package used was SAS (SAS Institute 1998).

An analysis of covariance (ANCOVA) was used to compare length-weight regression coefficients among stations. A Tukey's and Scheffe's test was used to examine differences among stations if the ANCOVA result was significant.

Results

Distribution

PWS hatchery pink salmon were found in all sampling periods. PWS hatchery fish comprised large percentages of samples in the GOA and PWS in July, as well as on the GOA shelf in August. By October, there were very few PWS hatchery pink salmon along the Seward hydrographic transect in the GOA.

GOA -July

In the GOA, a few pink salmon were found at nearshore stations in July. Unmarked fish are not necessarily wild pink salmon, since fish from other areas or hatcheries could be present (Table 1.3). Of the 21 fish sampled, 7 were unmarked, 9 were from different AFK release groups, and 4 from WNH.

PWS -July

Pink salmon were abundant at the six stations sampled in July in PWS. Unmarked fish in PWS were probably wild fish and were the most abundant group in catches (32-68%) (Table 1.3). CCH fish were the second most common fish sampled at the six stations, representing between 16 and 48% of the catches. Fish from AFK, WNH, and SGH were rarer in the samples (Table 1.3).

GOA -August

Five locations were sampled in the GOA in August. About 50 pink salmon were collected from each station and unmarked fish comprised the majority of all catches (Table 1.3). PWS hatchery fish comprised up to 32% of catches, and CCH and SGH were caught in the largest numbers.

GOA -October

In October, pink salmon were only found inshore of GAK 6 along the Seward hydrographic transect. Only two PWS hatchery (CCH) fish were sampled, the rest of the fish were unmarked (Table 1.3).

Lengths

Average pink salmon lengths ranged from 28.5 to 32.8 mm upon release from hatcheries (Figure 1.2, Table A-1.1). In July, pink salmon lengths ranged from 84.9 to 96.6 mm and by August, they were between 109.8 and 162.7 mm in length. Finally, by October, pink salmon were between 174.2 and 203.6 mm long (Figure 1.2, Table A-1.1). There were geographic variations in the average lengths of pink salmon within each sampling period. In August on the GOA shelf, pink salmon lengths varied considerably among stations. Fish sampled at the Cape Douglas stations were 25 to 53 mm longer than those sampled at the Cape Puget stations. In October, pink salmon at the outer stations were longer than those at nearshore stations along the Seward hydrographic transect (Figure 1.2, Table A-1.1).

Release -May

Pink salmon are released from hatcheries at approximately 30 mm standard length. CCH early released fish (28.5 mm) were the shortest fish on average; whereas, WNH early released fish (32.8 mm) were the longest (Figure 1.2, Table A-1.1). Late released fish tend to be larger. For example, AFK late released pink salmon were about 45.6 mm long.

GOA -July

Several pink salmon were sampled in the GOA in July with gillnets. The average standard length of those fish sampled was 87.4 mm (Figure 1.2, Table A-1.1). An ANOVA could not be performed to test for differences in lengths among stations because not enough fish were sampled. Four AFK early release fish ranged from 82-91 mm in length; whereas, five late release AFK fish were 85 to 93 mm.

PWS -July

The mean lengths of pink salmon in PWS in July were similar to fish in the GOA in July and ranged from 70.5 to 95.7 mm, at S1 and S2, respectively (Figure 1.2, Table A-1.1). Lengths were significantly different among stations. Fish at S2 were significantly longer than fish at all other stations except N2 (88.1 mm) ($p<0.05$). Fish at N2 were significantly longer than those sampled at N1 (77.8 mm) ($p<0.05$) (Figure 1.2, Table A-1.1).

CCH fish occurred at all six stations in PWS and were the shortest fish sampled (71.7 to 87.5 mm) (Figure 1.3, Table A-1.2). SGH fish were found at two stations in PWS and were the longest (94.3 to 105.6 mm) (Figure 1.3, Table A-1.2). WNH pink salmon occurred at three stations in PWS (C1, C2, and S2) and ranged from 86 to 96.2

mm in length (Figure 1.3, Table A-1.2). Three early release AFK salmon at two stations in PWS were 87-91 mm in length.

GOA -August

In August, mean lengths of pink salmon in the GOA ranged from 109.8 mm (CP2) to 162.7 mm (CD2) (Figure 1.2, Table A-1.1), with a significant difference among stations ($p<0.0001$). All stations were significantly different from each other; CD2 fish were the longest fish sampled and CP2 fish the shortest.

CCH fish sampled at CP2 were only about 1 mm shorter on average than WNH fish (Figure 1.3, Table A-1.2). SGH pink salmon (123.8 mm) were only sampled at GP but were much longer than CCH or WNH fish (Figure 1.3, Table A-1.2). Five early release AFK fish were sampled at three stations and were 97-105 mm in length.

GOA -October

Lengths of fish in October were also significantly different among stations on the Seward hydrographic transect ($p<0.05$). Lengths increased with distance from shore, as fish were shortest at GAK1 (174.2 mm) and longest at GAK6 (203.6 mm) (Figure 1.2, Table A-1.1). Fish at GAK6 were significantly longer than fish at GAK 1 and 2 ($p<0.05$). Not enough PWS hatchery pink salmon were sampled in the fall to examine their lengths separately.

Weights

Average wet weights of pink salmon upon release from hatcheries ranged from 0.18 (CCH early) to 0.87 g (AFK late) (Figure 1.4, Table A-1.3). By July pink salmon weighed between 4.5 and 11.4 g and by August weights ranged from 15.1 to 53.6 g. In October, pink salmon weights ranged from 70.0 to 113.6 g. There were significant differences in mean weights among stations within sampling periods. In August, the difference in fish weights at Cape Puget and Cape Douglas was as high as 38.5 g. Fish tended to be heavier at the outer stations along the Seward hydrographic transect in October (Figure 1.4, Table A-1.3).

Release -May

Wet weights of pink salmon released from hatcheries ranged from 0.18 (CCH early) to 0.87 g (AFK late) (Figure 1.4, Table A-1.3). Later released fish were heavier than those released earlier. The mean weight of hatchery fish was 0.26 g.

GOA -July

In the GOA, pink salmon in July weighed between 8.3 and 10.4 g (Figure 1.4, Table A-1.3). There were not enough fish samples to examine differences in weights among stations, or to examine weights of PWS hatchery fish. Four fish sampled at two stations were from the AFK early release group and weighed between 7.7 and 10.3 g.

PWS -July

In July, mean weights of pink salmon in PWS ranged from 4.5 to 11.4 g (Figure 1.4, Table A-1.3), with significant differences among stations ($p<0.0001$). Fish at S2 were the heaviest and those at S1 were the lightest. Only two (N1:C2, C1:C2) inter-station comparisons were not significantly different.

CCH fish (6.1 to 8.4 g) sampled at the six stations weighed less than WNH fish (8.1 - 11.51 g), and SGH fish (10.1 - 14.6 g) were the heaviest (Figure 1.5, Table A-1.4). The three early-release AFK salmon caught in PWS weighed 8.0 to 9.7 g.

GOA -August

Pink salmon sampled in the GOA in August varied considerably in mean weights, (15.1 - 53.6 g, Figure 1.4, Table A-1.3). Weights were significantly different among all stations ($p<0.05$), with the lightest fish at CP2 (15.1 g) and the heaviest fish at CD2 (53.6 g).

CCH and WNH fish had similar mean weights (13.2 and 13.3 g) at CP2; whereas, SGH fish were much heavier at GP (23.1 g) (Figure 1.5, Table A-1.4). Five early release AFK salmon were caught at three stations and weighed between 9.7 and 17.6 g.

GOA -October

In October, pink salmon over the GOA shelf had mean weights that ranged from 70.0 g (GAK1) to 113.6 g (GAK6) (Figure 1.4, Table A-1.3), with significant differences among stations. Fish at GAK6 were significantly heavier than fish GAK1 ($p<0.05$).

Length-Weight Regression

For all pink salmon sampled in 1998, wet weight was positively related to the standard length of pink salmon (R^2=0.99), with slightly more scatter associated with the smaller fish (Figure 1.6 and Table 1.4). There were no significant differences among fish sampled in PWS in July. The intercept of the regression was higher in PWS than in the GOA in July. There were significant differences in intercepts among stations in August and October. In August, the intercepts ranged from -5.6 at CP1 and GP to -5.7 at CD2 (Table 1.4). In October, the intercepts ranged from -4.2 (GAK 6) to -7.0 (GAK 1) (Table 1.4).

GOA –July

There were not enough fish sampled in July on the GOA shelf to perform an ANCOVA. The intercept of the log-transformed length-weight regression was –3.7 (Table 1.4).

PWS -July

Despite differences in lengths and weights among pink salmon sampled at different stations in PWS in July, there were no significant differences in the slopes or intercepts of the log-transformed length-weight regressions (Table 1.4). The intercept of the regression was lower, –4.8, than that from July in the GOA.

GOA -August

There were significant differences in log-transformed length-weight regressions among stations in August in the GOA. The intercepts of the regressions were significantly different among all stations ($p<0.05$) (Table 1.4). The intercepts were higher than the intercept from July in PWS, with the lowest at CD2 (-5.7) and highest at GP (-5.6).

GOA -October

In October, there was also a significant difference in the intercepts of the length-weight regressions among the stations sampled. Fish at all stations except GAK 4 and 6 were significantly different from each other ($p<0.05$) (Table 1.4). The difference in intercepts among stations in October was much larger than that in August. The intercept was lowest at GAK 1 (-7.0) and highest at GAK 6 (-4.2).

Growth Estimation

Estimated growth rates of PWS hatchery pink salmon ranged from 3.6 to 6.7% body weight per day (Table 1.5). CCH fish had higher growth rates than SGH or WNH fish. Growth rates were similar in PWS and on the GOA shelf in July.

If all CCH fish that were captured in PWS (July) were from the early release CCH group, estimated growth rates would be estimated as 3.63 to 4.57% body weight per day (Table 1.5). Estimated growth rates increased if captured fish were assumed to come from the mid- or late release groups because fish would have spent less time in the ocean to achieve the same weight. Growth rates of fish, assuming they came from the late release group, ranged from 5.19 to 6.66% body weight per day (Table 1.5). Growth rates for CCH pink salmon sampled in August (GOA) ranged from 4.22 to 5.65% body weight per day.

Growth rate estimates for SGH fish were slightly lower than estimates for CCH fish, due to the larger release size of SGH fish (Table 1.5). Assuming all captured SGH fish were from the early release group, growth rate estimates ranged from 3.74 to 4.04% body weight per day (Table 1.5). Estimates of growth rate increased when it was assumed all captured fish were from mid and late release groups. Assuming all captured SGH fish were from the late release group, growth rates estimates ranged from 5.34 to 5.82% body weight per day. Growth rate estimates for fish from release to July (PWS) and from release to August (GOA) were similar (Table 1.5).

The growth rate estimates of WNH fish were similar to those for SGH early release fish. All fish included in these growth estimates were from WNH early release fish and ranged from 3.61 to 4.01% body weight per day, depending on the station where the fish were captured (Table 1.5). The growth rates of fish from release to July (PWS) were slightly higher than the estimated growth rate of fish from release to August (GOA) (Table 1.5).

Energy Content

The mean energy content of juvenile pink salmon upon release from hatcheries ranged from 4,975 (AFK late) to 5,542 (WNH) cal/g dry weight (Figure 1.7 and Table A-

1.5). In July, fish on the GOA shelf had a higher energy content (4,845 cal/g dry weight) than those in PWS (4,370-4,780 cal/g dry weight) (Figure 1.7 and Table A-1.5). Fish on the GOA shelf maintained a high energy content in August (4,757-4,914 cal/g dry weight). Mean energy content decreased slightly in October, with values ranging from 4,662 to 4,794 cal/g dry weight. There were significant differences in energy content among stations within each sampling period, with no discrete pattern.

Release -May

Upon release from hatcheries, pink salmon vary in condition. The energy content of fish from the AFK early release was 4,978.4 cal/g dry weight (Figure 1.7, Table A-1.5). The fish with the highest energy content were the early release fish from WNH (5,262.1 cal/g dry weight).

GOA -July

Fish on the GOA shelf in July had energy contents only slightly lower than hatchery released fish. Fish at GAK2i had an average energy content of 4,845.3 cal/g dry weight (Figure 1.7, Table A-1.5). Only two AFK early release fish were examined for their energy content and those values were 4,803 and 4,810 cal/g dry weight.

PWS -July

The energy content of pink salmon sampled in PWS was lower the energy content of fish sampled upon release from hatcheries and those sampled in the GOA in July.

Values ranged from 4,370.0 (C1) to 4,779.7 (N2) cal/g dry weight (Figure 1.7, Table A-1.5), with significant differences among stations ($p<0.05$). Fish sampled at N2 had a significantly higher energy content than fish sampled at other stations except S2 (4,601.3 cal/g dry weight) and C2 (4,522.3 cal/g dry weight).

The energy content of CCH, SGH, and WNH fish ranged from 4,306 to 4,575 cal/g dry weight (Figure 1.8, Table A-1.6). Two early release AFK fish had 4,651 and 4,707 cal/g dry weight.

GOA -August

The energy content of pink salmon sampled in August in the GOA was higher than those sampled in July in PWS, with values ranging from 4,756.6 (CP1) to 4,914.4 (CD2) cal/g dry weight (Figure 1.7, Table A-1.5), with significant differences among stations ($p<0.0001$). Fish sampled at CP1 and GP had significantly lower energy content than all other stations ($p<0.05$).

Both CCH and WNH salmon had similar energy content at CP2 (4,877.9 and 4,862.3 cal/g dry weight) (Figure 1.8, Table A-1.6). SGH fish at GP had an average energy content of 4,787.3 cal/g dry weight. Five early release AFK fish ranged from 4,757 to 4,947 cal/g dry weight.

GOA -October

The energy contents of fish sampled in October were slightly lower than those sampled in August on the GOA shelf, with significant differences among stations

($p<0.001$). Fish at GAK 2 (4,466.2 cal/g dry weight) had a significantly lower energy content than those at GAK stations 4 (4,725.3 cal/g dry weight) and 5 (4,793.7 cal/g dry weight) ($p<0.05$) (Figure 1.7, Table A-1.5). Fish with the highest energy content were at GAK 5.

Energy content as a function of percent dry weight

The relationship of energy content as a function of percent dry weight (Tables A-1.7 and A-1.8) for all pink salmon sampled in 1998 was weakly negative (R^2= 0.03, Figure 1.8 and Table 1.6). This is unexpected, since percent dry weight is often positively correlated with energy content and often used as a proxy for energy content. The low dry weights and high energy content of fish sampled from hatchery releases provided quite a bit of variability and scatter. The regression of energy content as a function of percent dry weight did not provide a strong relationship in any of the time periods sampled (R^2 values ranged from 0.002 to 0.28, Figure 1.8 and Table 1.6).

Discussion

The samples in this study may be representative of the 1997 brood year of pink salmon because the samples were taken at appropriate locations and times within their known migration route and duration. Pink salmon enter PWS in late April to May and are thought to utilize shallow bays and stay in PWS for up to four months (Cooney et al. 1978). Pink salmon then move out onto the shelf and migrate westward along the shelf (Farley and Munk 1997). Pink salmon were sampled in July in PWS and on the GOA shelf in July, August, and October. PWS hatchery pink salmon were caught in all sampling periods.

Fish samples were collected with a variety of gear types of varying gear selectivities, preventing direct data comparisons between sampling periods. Pink salmon were sampled with a purse seine in PWS, and with gillnets in the GOA in July; however, fish from both sampling locations were of the same length. This may indicate that the purse seine and gillnets sampled fish of comparable sizes. The utilization of different gear types to sample juvenile pink salmon seasonally is unavoidable due to the change of fish size and location with time.

Juvenile pink salmon were abundant in northeast, central, and southwest PWS in July, as expected. It appears that some pink salmon leave PWS prior to completing a four-month residence period in the Sound, since there were PWS hatchery pink salmon on the GOA shelf in July. Fish from the AFK hatchery were not abundant in PWS in July; however, they did represent a large proportion of fish sampled in the GOA in July. AFK hatchery is located in southwest PWS, and it is possible that fish from that hatchery go directly to the GOA, without spending much time in the PWS. PWS hatchery pink salmon were found as far Cape Douglas (approximately 350 km from PWS) in August, yet some CCH pink salmon were still found on the shelf (along the Seward hydrographic transect) approximately 90 km from PWS in October. This protracted migration of juvenile pink salmon could be a function of the release dates or fish growth. Cooney et al. (1978) found that pink salmon moved from shallow bays once they reached 60-70 mm in length. In this study it was found that pink salmon lengths varied among stations sampled in PWS; therefore, the time that they moved to deeper waters may have also varied among stations.

Juvenile pink salmon lengths, weights, and condition varied geographically within each sampling period. The variation in fish weights among stations within each sampling period resulted in a geographic variation in the growth estimates. Juvenile pink salmon in PWS have been estimated to grow between 2.56 to 8.13% body weight per day in May and June, depending on year and release group (Willette et al. 1994). Most growth estimates by Willette et al. (1994) were between 3 and 5% body weight per day. In this study, juvenile pink salmon grew in body weight at 3.63 to 6.7% per day. The estimates of growth rates in this study do not take into account size-selective mortality or gear selectivity, however, they are within the range of values estimated by Willette et al. (1994) using coded wire tags. The estimated growth rates for CCH fish were slightly higher than those estimated for other hatchery groups. This could be a function of release dates, release weights, and/or capture weights.

Energy content of fish is often predicted utilizing the dry weight of fish (Hartman and Brandt 1995). Energy content is positively related to percent dry weight for juvenile pollock, and herring (Boldt 1997). The correlation of energy content with percent dry weight was weak and negative. Percent dry weight does not appear to be a reliable predictor of juvenile pink salmon energy content.

Pink salmon at the time of release from hatcheries had the highest energy content per unit weight, probably because they have been fed at the hatcheries. The average energy content in July in PWS was much lower (4,370-4,780 cal/g dry weight or approximately 3.9 kJ/g wet weight). The energy content values in this study are similar to those found by Paul (1997) for pink salmon in late May to early June - 3.2 to 4.4 kJ/g wet weight. At the same time, pink salmon on the GOA shelf in July had higher energy contents than those in PWS. In August, energy contents were also high, but then decreased slightly in October. The energy contents of the CCH and WNH cohorts showed a similar pattern. All fish from CCH, SGH, and WNH had a higher energy content in July and August on the GOA shelf than fish in July in PWS. The low energy content of fish in PWS in July may be indicative of poorer feeding conditions compared to the GOA in August. The increase in fish energy content in August may indicate that the best time and place for growth of juvenile pink salmon is in August on the GOA shelf.

It is thought that there is strong size selective mortality in the early life history of fishes (Healey 1982). It is possible that the observed increase in fish energy content on the GOA shelf in August, relative to PWS in July, was the result of size-selective mortality. If only large, high-energy fish are able to escape predation, only those fish will be observed on the GOA shelf. Small, slow growing fish would, therefore, be expected to have lower survival rates than larger fish. CCH were the shortest and SGH were the longest pink salmon sampled in PWS in July. If size-selective predation was important in determining survival, CCH fish would have a lower survival than SGH pink salmon. The survival rate of CCH and SGH fish can be estimated from the number of fry released in 1998 and the number of returns in 1999. CCH pink salmon had a survival rate of 5.6%, whereas, SGH pink salmon had a survival rate of 8.6% (D. Reggiani, Prince William

Sound Aquaculture Corporation, personal communication; SGH personnel, personal communication), supporting the hypothesis that size-selective predation is an important determinant of fish survival.

It is important to note, however, that fish sampled in July on the GOA shelf and in PWS were comparable in length, but the fish on the shelf were in better condition than those sampled in PWS. This indicates that size-selective mortality may not be the only cause of the increase fish condition observed on the GOA shelf. The GOA shelf may have had better feeding and growing conditions than PWS in July.

Summary

Juvenile pink salmon appeared to occupy PWS from the time of their release in May to at least mid-July. Some pink salmon, such as those released from AFK and possibly wild pink salmon from the southwest corner of PWS, may have moved directly to the GOA shelf without spending as much time in PWS as fish from other areas or hatcheries. By August, there were many PWS hatchery pink salmon on the GOA shelf and some had moved west of PWS about 340 km. In October, a few PWS hatchery pink salmon were still found on the GOA shelf near PWS; however, it appeared that most PWS pink salmon had moved out of the area. Sampling in October indicated that juvenile pink salmon were constrained to the shelf and not found offshore of the slope.

The energy content of juvenile pink salmon varied among stations sampled in each time period. Pink salmon in PWS grew at an estimated rate of approximately 3.6 to 6.7% body weight per day. In August, growth rates were similar to those estimated for fish sampled in July (3.6-5.6% body weight per day). Differences in fish lengths, weights, condition, and estimated growth rates could be due to geographic variations in feeding conditions. The energy content of fish in July and August on the GOA shelf was higher than that of fish sampled at any other time or location (except upon release), indicating that July and August on the GOA shelf may have been the best period examined for juvenile pink salmon growth.

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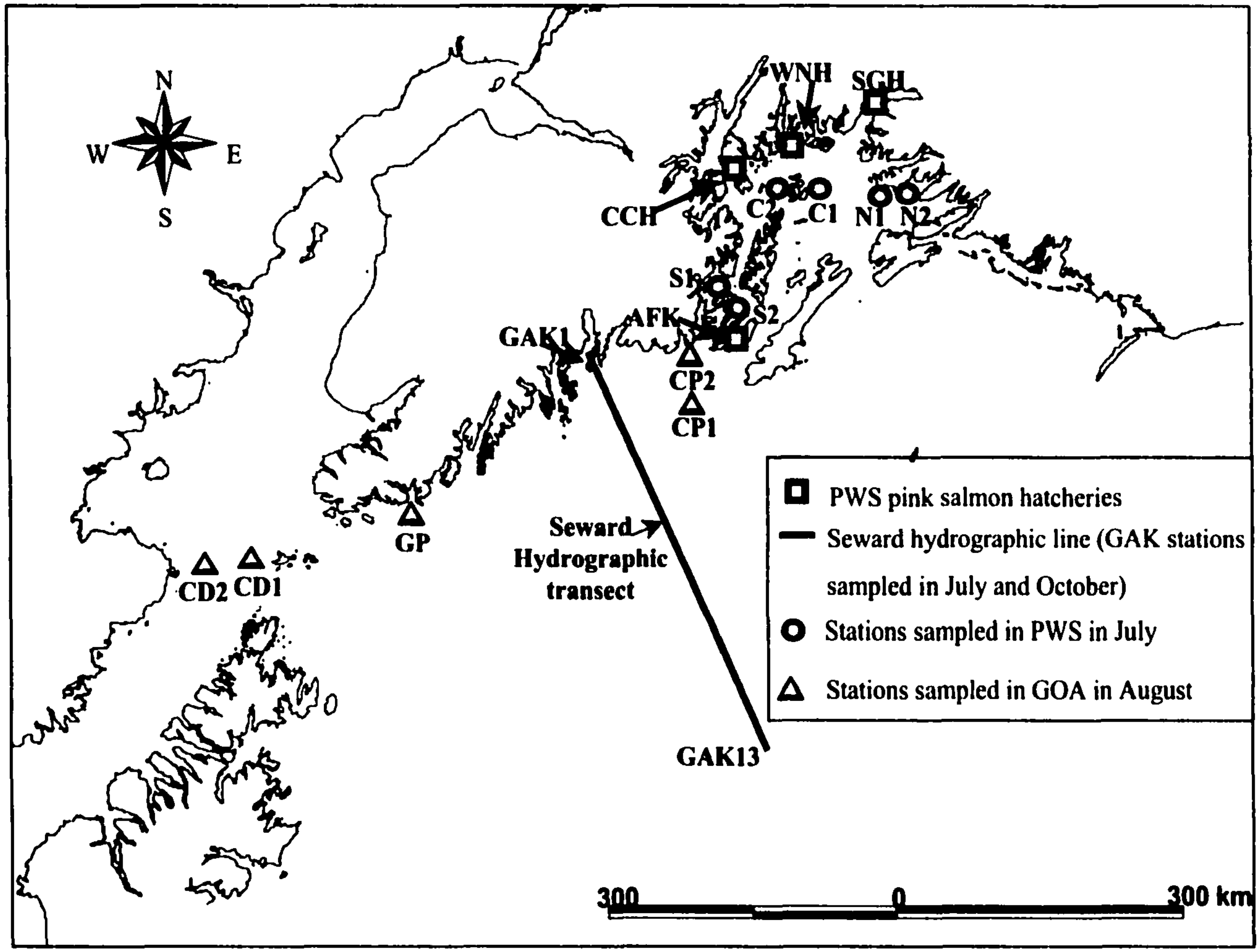

Figure 1.1. Sampling locations in PWS and the GOA in 1998. There are four pink salmon hatcheries in PWS (SGH, WNH, CCH, AFK). Six stations were sampled in PWS in July (N1, N2, C1, C2, S1, S2). Stations along the Seward hydrographic transect were sampled in July and October. Main stations are located every 18.5 km along the Seward transect (intermediate stations, such as GAK1i, are halfway between main stations). Five stations were sampled in the GOA in August (CP1, CP2, GP, CD1, CP2).

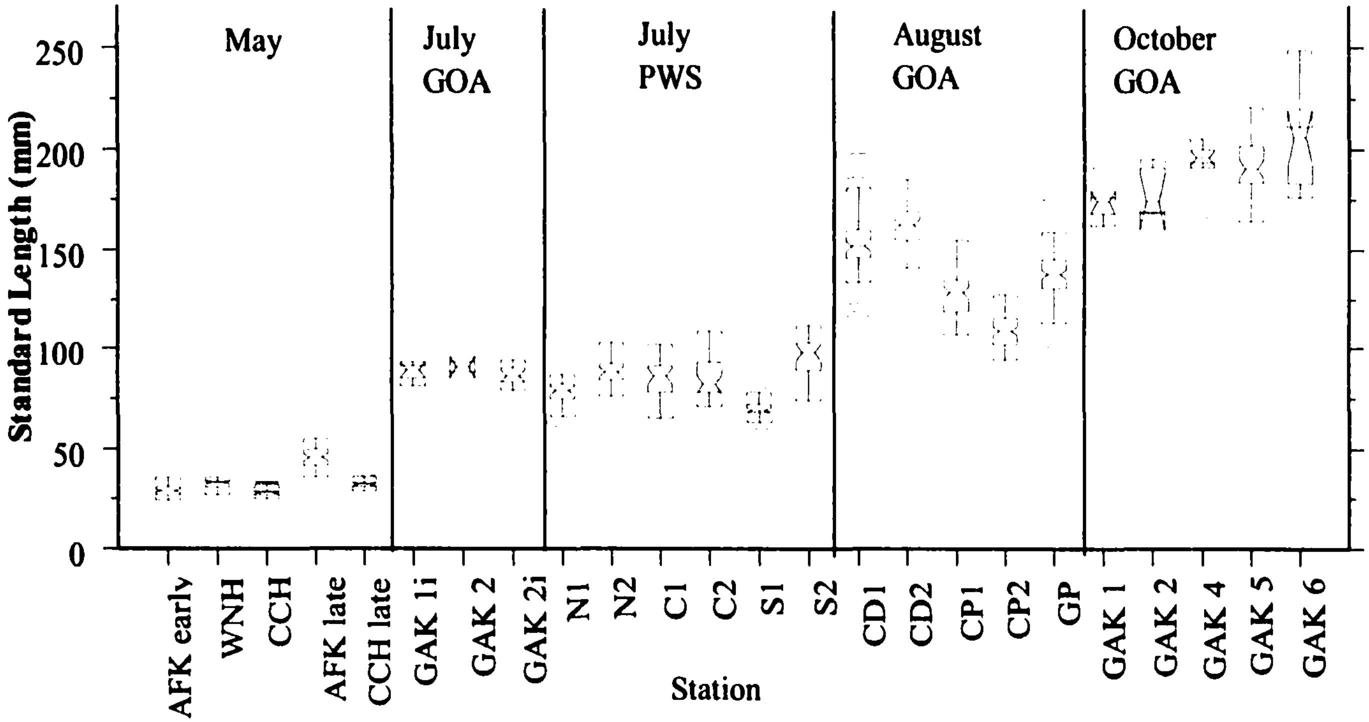

Figure 1.2. Notched box plots of pink salmon standard lengths sampled in five time periods.

AFK early, AFK late, CCH early, CCH late, and WNH early were samples of pink fry from PWS hatcheries in May.

N1 and N2 are in northeast PWS; C1 is in east central PWS; C2 is in west central PWS; S1and S2 are in southwest PWS.

GAK stations are along the Seward hydrographic transect in the NGOA.

Station GAK 1 is nearshore and GAK 6 is near the shelf break.

CD1 and CD2 are stations near Cape Douglas. CP1 and CP2 are stations near Cape Puget.

GP is a station near Gore Point.

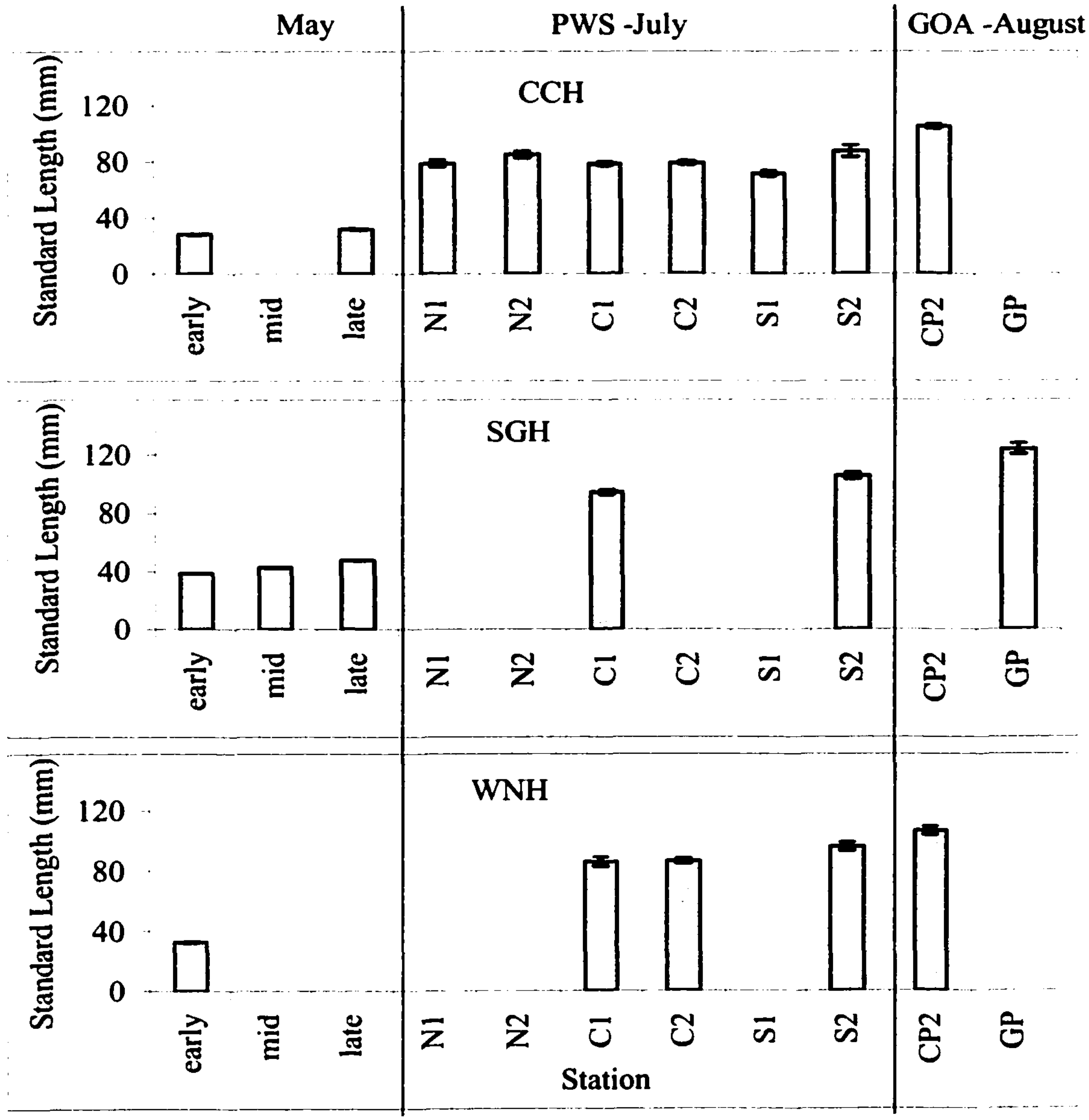

Figure 1.3. Average standard lengths, with standard error bars, of CCH, SGH, and WNH pink salmon. Thermally marked fish were sampled at release (early, mid-, and late), in PWS in July at six stations (N1, N2, C1, C2, S1, and S2); and in the GOA in August at two stations (CP2 and GP). Lengths of SGH hatchery releases were provided by the Alaska Department of Fish and Game (personal communication).

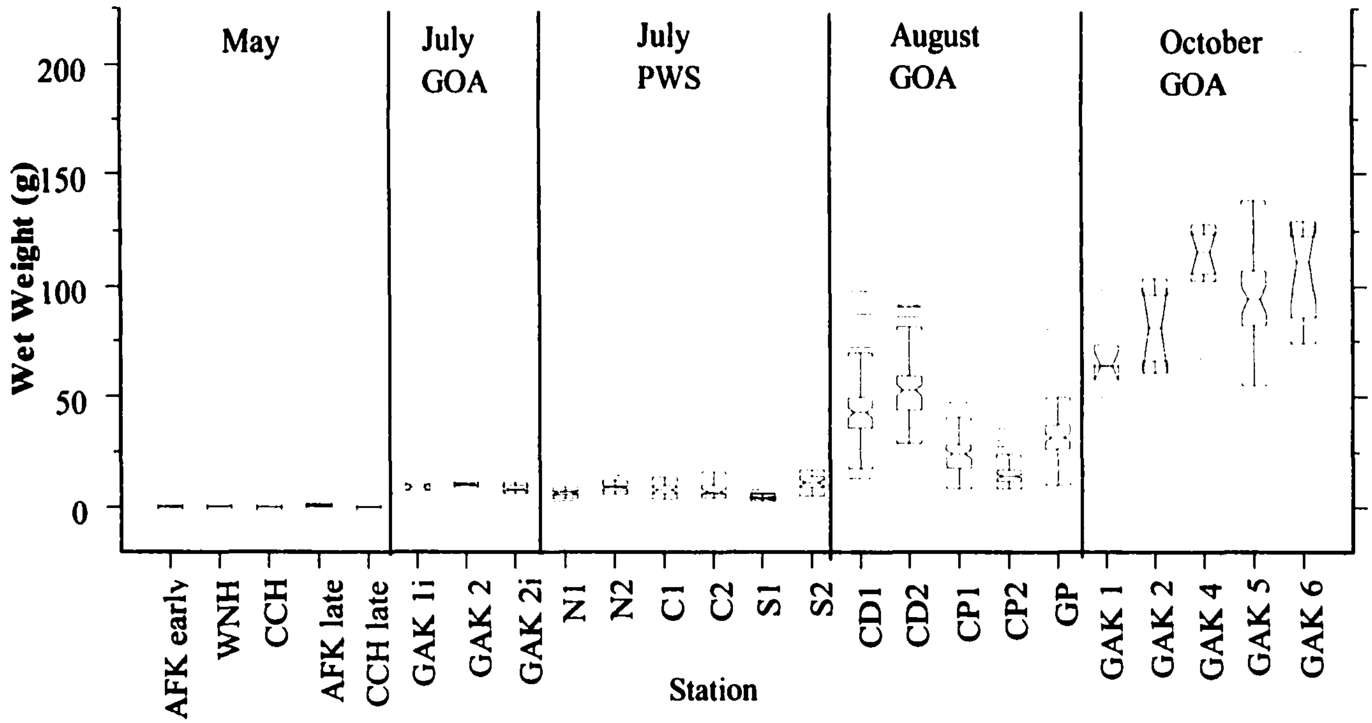

Figure 1.4. Notched box plots of pink salmon wet weights sampled in five time periods.

AFK early, AFK late, CCH early, CCH late, and WNH early were samples of pink fry from PWS hatcheries in May.

N1 and N2 are in northeast PWS; C1 is in east central PWS; C2 is in west central PWS; S1and S2 are in southwest PWS.

GAK stations are along the Seward hydrographic transect in the NGOA.

Station GAK 1 is nearshore and GAK 6 is near the shelf break.

CD1 and CD2 are stations near Cape Douglas. CP1 and CP2 are stations near Cape Puget.

GP is a station near Gore Point.

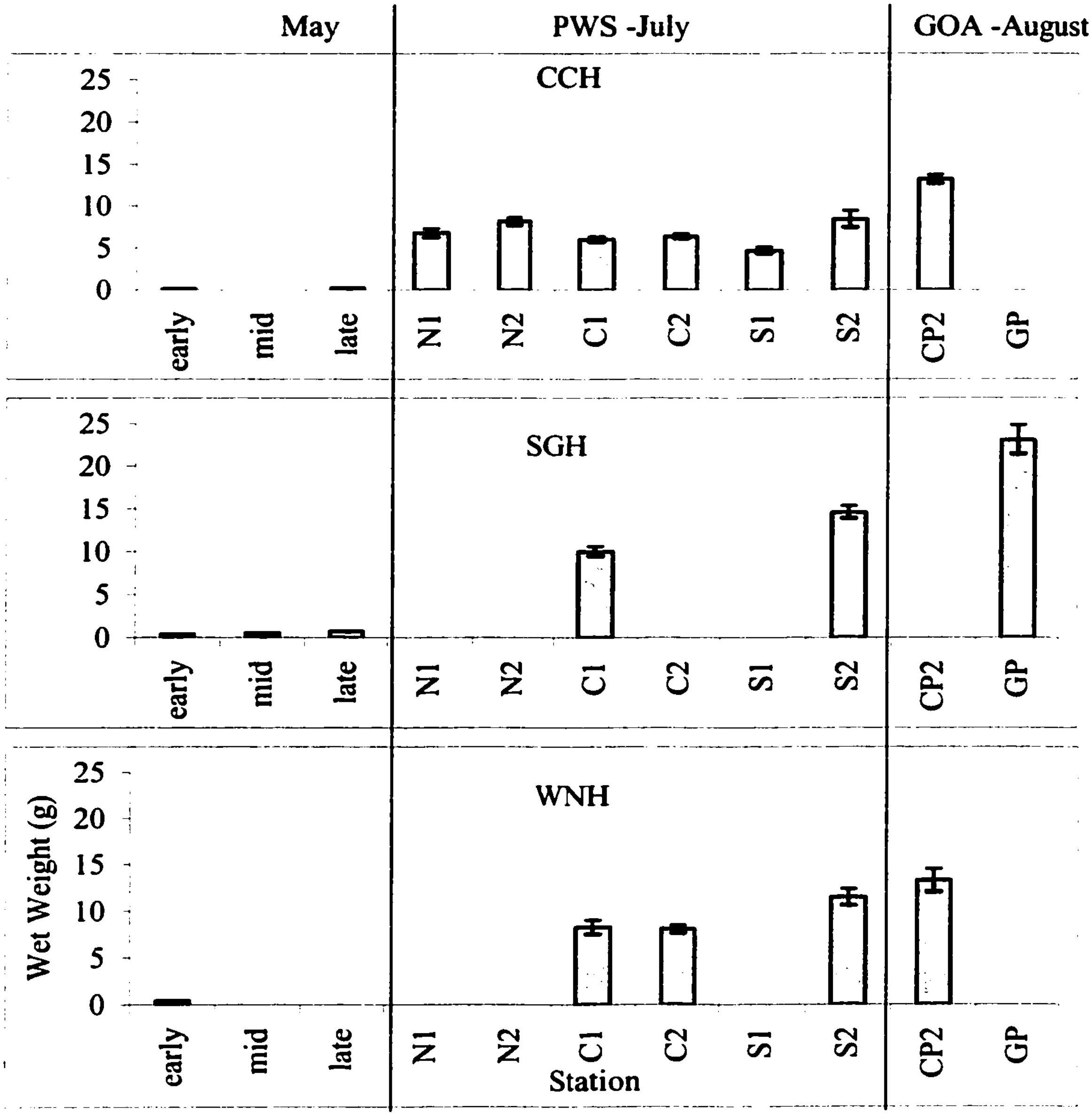

Figure 1.5. Average wet weights, with standard error bars, of CCH, SGH, and WNH pink salmon. Thermally marked fish were sampled at release (early, mid-, and late), in PWS in July at six stations (N1, N2, C1, C2, S1, and S2); and in the GOA in August at two stations (CP2 and GP). Weights of SGH hatchery releases were provided by the Alaska Department of Fish and Game (personal communication).

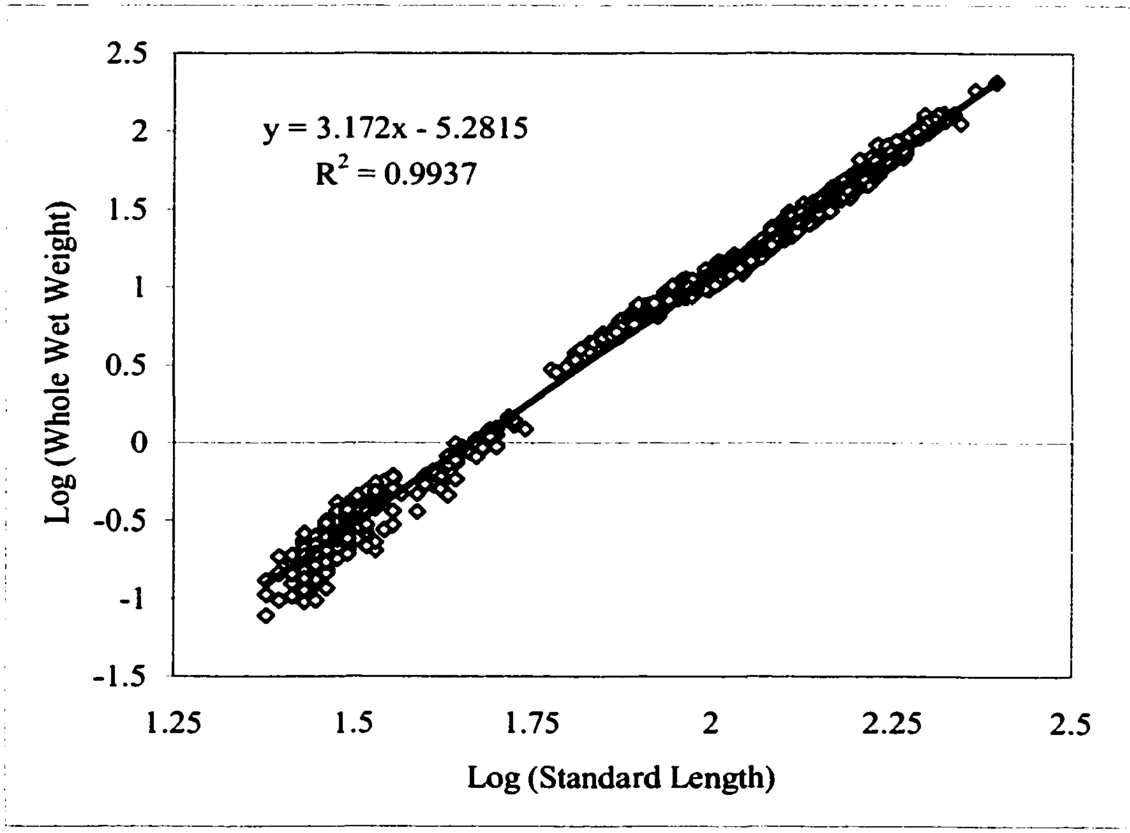

Figure 1.6. Log-transformed length-weight regression for all juvenile pink salmon sampled at all stations and in all sampling periods in 1998. The equation and R^2 value for the linear trendline are shown. Lengths were measured in mm and weight in g.

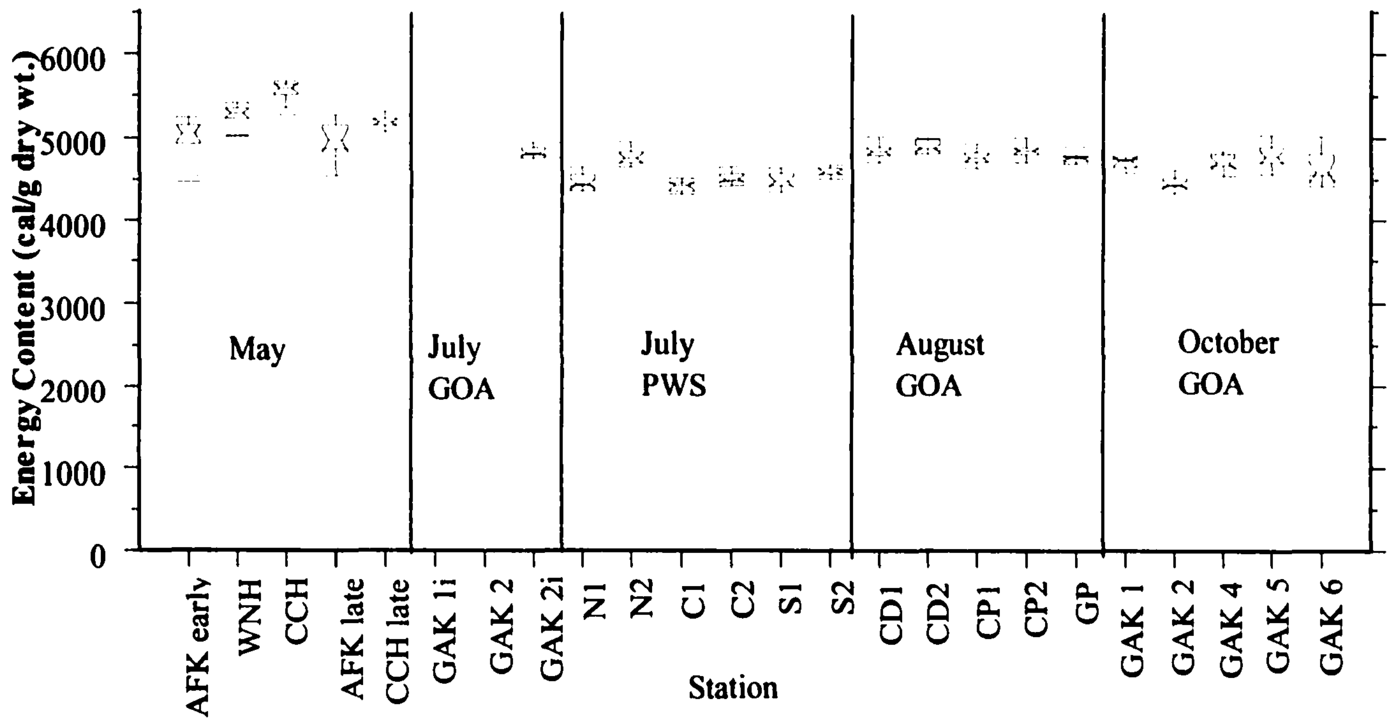

Figure 1.7. Notched box plots of pink salmon energy content sampled in five time periods.

AFK early, AFK late, CCH early, CCH late, and WNH early were samples of pink fry from PWS hatcheries in May.

N1 and N2 are in northeast PWS; C1 is in east central PWS; C2 is in west central PWS; S1and S2 are in southwest PWS.

GAK stations are along the Seward hydrographic transect in the NGOA.

Station GAK 1 is nearshore and GAK 6 is near the shelf break.

CD1 and CD2 are stations near Cape Douglas. CP1 and CP2 are stations near Cape Puget.

GP is a station near Gore Point.

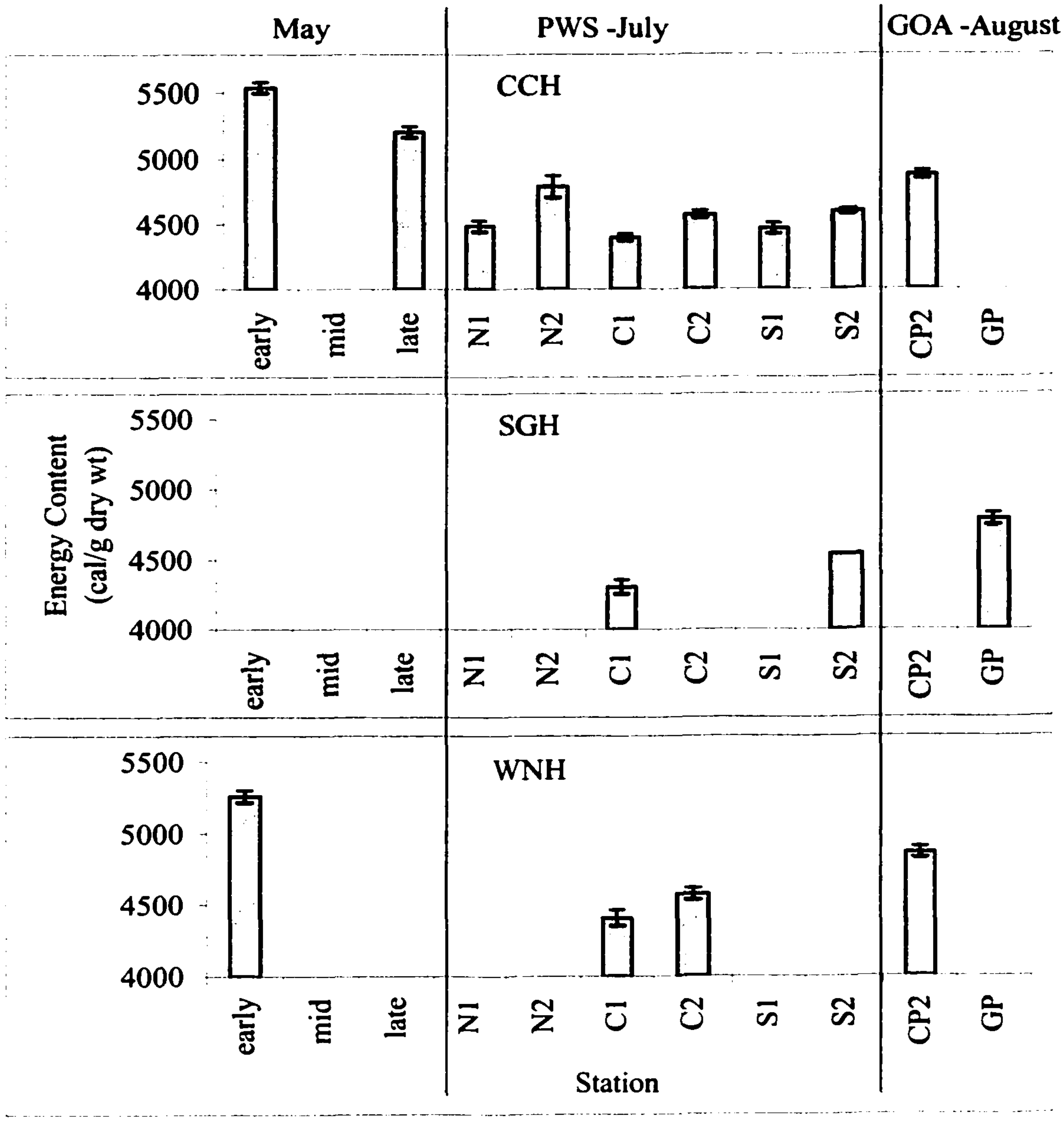

Figure 1.8. Average energy content, with standard error bars, of CCH, SGH, and WNH pink salmon. Thermally marked fish were sampled at release (early, mid-, and late), in PWS in July at six stations (N1, N2, C1, C2, S1, and S2); and in the GOA in August at two stations (CP2 and GP). Only one SGH fish was sampled at S2.

Table 1.1. Areas and dates of pink salmon samples collected in 1998.
PWSAC: Prince William Sound Aquaculture Cooperation
APEX: Apex Predator Ecosystem Experiment
GLOBEC: Global Ocean Ecosystem Dynamics Program
OCC: Ocean Carrying Capacity Project
PWS: Prince William Sound
GOA: Gulf of Alaska

Project	Area	Dates	Gear Used	Number of Stations Sampled
PWSAC	PWS	May 1-29	upon release	5
GLOBEC	GOA	July 10-15	Gillnet	4
APEX	PWS	July 15-19	Purse Seine	6
OCC	GOA	August 1-3	Surface Trawl	5
GLOBEC	GOA	October 2-9	Gillnet	5

Table 1.2. Dates and stations where samples were collected. Numbers of pink salmon measured, dried, and examined for energy content are shown.

	Area	Date	Station	Latitude (deg. min.)		Longitude (deg. min.)		# pink salmon measured and dried	# pink salmon examined for energy content
PWSAC	PWS	May 8	AFK early					50	10
		May 24	AFK late					47	10
		May 7	CCH early					50	10
		May 29	CCH late					21	10
		May 1	WNH early					50	10
GLOBEC	GOA	July 15	GAK 1i	59	46.24	149	23.32	6	0
		July 14	GAK 2	59	41.54	149	19.66	2	0
		July 7 and 14	GAK 2i	59	36.39	149	18.29	13	10
APEX	PWS	July 15	N1	60	38.89	146	27.69	25	10
		July 15	N2	60	39.54	146	36.03	25	10
		July 16	C1	60	37.92	147	15.57	105	30
		July 17	C2	60	38.85	147	37.87	61	29
		July 18	S1	60	13.61	148	10.57	25	11
		July 19	S2	60	12.06	148	4.75	25	9
OCC	GOA	August 3	CD1	58	50.14	152	20.36	83	16
		August 3	CD2	58	50.40	152	44.98	94	11
		August 1	CP1	59	26.46	148	26.34	81	14
		August 1	CP2	59	55.17	148	26.82	91	30
		August 2	GP	59	10.09	150	55.65	93	15
GLOBEC	GOA	October 4	GAK 1	59	50.05	149	29.18	6	6
		October 8	GAK 2	59	41.49	149	20.05	5	5
		October 8	GAK 4	59	24.51	149	3.34	10	10
		October 8	GAK 5	59	18.24	148	53.33	12	12
		October 6	GAK 6	59	6.48	148	45.96	8	8

Table 1.3. Number of Prince William Sound hatchery fish sampled at different times and locations.
AFK = Armin F. Koernig Hatchery; CCH = Cannery Creek hatchery
SGH = Solomon Gulch hatchery; WNH = Wally Noerenberg hatchery
+' = indicates a late release group; ? = unknown; U = unmarked

Project	Area	Date	Station	AFK	AFK 2+	AFK 3+	CCH	SGH	WNH	WNH 3+	WNH+	?	U	Total
GLOBEC	GOA	July 15	GAK 1i	2		1			1			0	2	6
		July 14	GAK 2							1		0	1	2
		July 14	GAK 2i	2		4	1			1		0	2	10
		July 7	GAK 2i						1			0	2	3
			sum	4	0	5	1	0	2	2	0	0	7	21
APEX	PWS	July 15	N1				6	1				1	17	25
		July 15	N2	2			7	1	2		2	0	11	25
		July 16	C1		1	1	38	8	7		5	3	42	105
		July 17	C2	1			17	3	9		6	0	25	61
		July 18	S1				12	1				0	12	25
		July 19	S2				4	5	6			2	8	25
			sum	3	1	1	84	19	24	0	13	6	115	266
OCC	GOA	August 3	CD1	1				3				3	42	49
		August 3	CD2					1				0	49	50
		August 1	CP1				1				3	2	44	50
		August 1	CP2	3		1	8		4		2	7	25	50
		August 2	GP	1				4				1	44	50
			sum	5	0	1	9	8	4	0	5	13	204	249
GLOBEC	GOA	October 4	GAK 1									0	5	5
		October 8	GAK 2				1					0	5	6
		October 8	GAK 4									0	8	8
		October 8	GAK 5				1					1	21	23
		October 6	GAK 6									0	10	10
			sum	0	0	0	2	0	0	0	0	1	49	52

Table 1.4. Slopes, intercepts, and R^2 values for the log-transformed length-weight regressions. Regression results are shown for all sampling periods. Regression results are shown for individual stations where there were significant differences in intercepts among stations.

Project	Area	Station	Event/Gear	Slope	Std error	Intercept	Standard error	R^2
PWSAC	PWS	Hatchery Releases		3.097	0.086	-5.183	0.130	0.858
GLOBEC	GOA	All stations		2.392	0.340	-3.696	0.660	0.723
APEX	PWS	All stations		2.936	0.034	-4.763	0.066	0.981
OCC	GOA	CD1	105	3.319	0.072	-5.616	0.156	0.964
		CD2	104	3.358	0.123	-5.705	0.273	0.890
		CP1	98	3.317	0.080	-5.621	0.169	0.956
		CP2	97	3.304	0.101	-5.574	0.206	0.923
		GP	101	3.298	0.086	-5.561	0.184	0.941
GLOBEC	GOA	GAK 1	4-1G	3.939	0.511	-6.99	1.146	0.952
		GAK 2	10-1G	2.714	0.842	-4.205	1.896	0.722
		GAK 4	9-1G	3.017	0.374	-4.861	0.856	0.916
		GAK 5	8-1G	3.085	0.190	-5.073	0.434	0.926
		GAK 6	6-1G	2.687	0.307	-4.160	0.709	0.905

Table 1.5. Growth estimates of juvenile PWS hatchery pink salmon. Growth rates were calculated using an exponential growth equation, weights and dates of fish at capture and release. Fish from CCH and SGH did not have unique thermal marks for early, mid, and late release groups. A range of growth rates for these fish was estimated by assuming all captured fish were from the early, mid, or late release.

Hatchery group	Area	Station	Date of release or capture	Range of weights released (g)	Wet weights used for growth estimates (g)	Time period from early release (days)	Growth from early release (% body weight/day)	Time period from mid release (days)	Growth from mid release (% body weight/day)	Time period from late release (days)	Growth from late release (% body weight/day)
CCH	Release	early	May 7	0.28-0.39	0.335						
	Release	mid	May 20	0.36-0.37	0.365						
	Release	late	May 29	0.33-0.42	0.375						
	PWS	N1	July 15		6.798	70	4.300%	57	5.131%	48	6.271%
	PWS	N2	July 15		8.191	70	4.567%	57	5.458%	48	6.660%
	PWS	C1	July 16		6.074	71	4.081%	58	4.848%	49	5.913%
	PWS	C2	July 17		6.430	72	4.104%	59	4.862%	50	5.909%
	PWS	S1	July 18		4.734	73	3.628%	60	4.271%	51	5.193%
	PWS	S2	July 19		8.436	74	4.360%	61	5.148%	52	6.204%
	GOA	CP2	August 1		13.219	87	4.224%	74	4.851%	65	5.654%
SGH	Release	early	April 23	0.420	0.420						
	Release	mid	May 5	0.520	0.520						
	Release	late	May 20	0.720	0.720						
	PWS	C1	July 16		10.054	85	3.736%	73	4.350%	58	5.475%
	PWS	S2	July 19		14.632	88	4.035%	76	4.672%	61	5.821%
	GOA	GP	August 2		23.110	102	3.929%	90	4.453%	75	5.344%
WNH	Release	early	May 1	0.39-0.54	0.465						
	PWS	C1	July 16		8.287	77	3.741%				
	PWS	C2	July 17		8.117	78	3.666%				
	PWS	S2	July 19		11.510	80	4.011%				
	GOA	CP2	August 1		13.310	93	3.607%				

Table 1.6. Slopes, intercepts, and R^2 values for the regression of energy content as a function of percent dry weight. Regression results are shown for all sampling periods.

Project	Area	Slope	Standard error	Intercept	Standard error	R^2
Releases	PWS	5,562.10	2,600.51	4,143.90	491.844	0.087
GLOBEC	GOA	5,643.30	3,988.01	3,606.20	875.851	0.200
APEX	PWS	-1,456.70	2,645.45	4,808.90	540.333	0.003
OCC	GOA	-631.41	1,511.53	4,970.90	329.889	0.002
GLOBEC	GOA	10,124.00	2,585.07	2,464.80	568.374	0.282
All periods	All areas	-3,540.90	1,205.19	5,504.30	251.789	0.030

APPENDIX

Table A-1.1. Average standard lengths of juvenile pink salmon sampled at different times and locations during their first six months at sea.

Project	Area	Date	Station	Event/Gear	Average standard length (mm)	n	Standard deviation	Standard error
PWSAC	PWS	May 8	AFKearly		29.060	50	2.958	0.418
		May 24	AFKlate		45.681	47	4.559	0.665
		May 7	CCHearly		28.480	50	1.764	0.249
		May 29	CCHlate		32.143	21	2.081	0.454
		May 1	WNHearly		32.820	50	2.413	0.341
GLOBEC	GOA	July 15	GAK 1i	30-1G	88.000	6	4.336	1.770
		July 14	GAK 2	27-1G	90.500	2	3.536	2.500
		July 7 + 14	GAK 2i	3-1G + 26-1G	86.615	13	4.770	1.323
APEX	PWS	July 15	N1	13-1U	78.000	25	6.583	1.317
		July 15	N2	16-1U	88.360	25	6.448	1.290
		July 16	C1	29-1U	84.943	105	8.512	0.831
		July 17	C2	35-1U	85.672	61	8.910	1.141
		July 18	S1	50-1U	70.480	25	5.716	1.143
		July 19	S2	65-1U	95.680	25	9.716	1.943
OCC	GOA	August 3	CD1	105	152.253	83	14.457	1.587
		August 3	CD2	104	162.702	94	10.844	1.118
		August 1	CP1	98	127.642	81	11.923	1.325
		August 1	CP2	97	109.824	91	8.689	0.911
		August 2	GP	101	137.516	93	12.268	1.272
GLOBEC	GOA	October 4	GAK 1	4-1G	174.200	5	10.872	4.862
		October 8	GAK 2	10-1G	178.500	6	11.572	4.724
		October 8	GAK 4	9-1G	193.750	8	12.045	4.258
		October 8	GAK 5	8-1G	191.696	23	15.089	3.146
		October 6	GAK 6	6-1G	203.600	10	22.077	6.981

Table A-1.2. Average standard lengths, sample sizes (n), and standard errors (se) of pink salmon from three hatchery groups. Lengths of fish sampled at time of release are shown for early, mid, and late released fish. Pink salmon sampled in July (PWS) and in August (GOA) were separted by their thermal marks and measured. CCH and SGH fish sampled in July and August could not be separated into early, mid, or late release groups by thermal marks. Fish from WNH were separated by release date, and only WNH early release are shown.

CCH= Cannery Creek Hatchery
SGH = Solomon Gulch Hatchery; lengths from Alaska Department of Fish and Game (personal communication).
WNH early = Wally Noerenberg Hatchery early release
N1 and N2 = stations in northeast PWS taken in July, 1998
C1 and C2 = stations in central PWS taken in July, 1998
S1 and S2 = stations in southwest PWS taken in July, 1998
CP2 = station in GOA taken in August, 1998
GP = station in GOA taken in August, 1998

Cohort	Station	Early	Mid	Late	N1	N2	C1	C2	S1	S2	CP2	GP
CCH	Standard length (mm)	28.480		32.143	79.000	85.286	78.526	79.294	71.667	87.500	105.250	
	n	50		21	6	7	38	17	12	4	8	
	se	0.249		0.454	2.236	2.032	1.261	1.150	1.725	4.052	1.411	
SGH	Standard length (mm)	39	43	48			94.250			105.600		123.750
	n						8			5		4
	se						1.485			2.015		3.637
WNH	Standard length (mm)	32.820					86.000	86.667		96.167	106.750	
early	n	50					7	9		6	4	
	se	0.341					2.895	1.546		2.496	2.594	

Table A-1.3. Average wet weights of juvenile pink salmon sampled at different times and locations during their first six months at sea.

Project	Area	Date	Station	Event/Gear	Average wet weight (g)	n	Standard deviation	Standard error
PWSAC	PWS	May 8	AFKearly		0.275	50	0.126	0.018
		May 24	AFKlate		0.873	47	0.307	0.045
		May 7	CCHearly		0.178	50	0.047	0.007
		May 29	CCHlate		0.264	21	0.067	0.015
		May 1	WNHearly		0.413	50	0.097	0.014
GLOBEC	GOA	July 15	GAK 1i	30-1G	9.056	6	1.219	0.498
		July 14	GAK 2	27-1G	10.437	2	0.653	0.462
		July 7 + 14	GAK 2i	3-1G + 26-1G	8.652	13	1.302	0.361
APEX	PWS	July 15	N1	13-1U	6.468	23	1.559	0.325
		July 15	N2	16-1U	9.141	25	1.900	0.380
		July 16	C1	29-1U	7.808	104	2.313	0.227
		July 17	C2	35-1U	8.120	61	2.656	0.340
		July 18	S1	50-1U	4.520	25	1.215	0.243
		July 19	S2	65-1U	11.391	25	3.076	0.615
OCC	GOA	August 3	CD1	105	43.937	83	13.921	1.528
		August 3	CD2	104	53.640	94	13.029	1.344
		August 1	CP1	98	23.953	81	7.670	0.852
		August 1	CP2	97	15.131	91	4.596	0.482
		August 2	GP	101	31.955	93	9.745	1.010
GLOBEC	GOA	October 4	GAK 1	4-1G	70.049	5	18.044	8.070
		October 8	GAK 2	10-1G	81.605	6	16.423	6.705
		October 8	GAK 4	9-1G	110.838	8	19.488	6.890
		October 8	GAK 5	8-1G	94.996	23	25.986	5.418
		October 6	GAK 6	6-1G	113.585	10	37.898	11.984

Table A-1.4. Average wet weights, sample sizes (n), and standard errors (se) of pink salmon from three hatchery groups. Weights of fish sampled at time of release are shown for early, mid, and late released fish. Pink salmon sampled in July (PWS) and in August (GOA) were separted by their thermal marks and measured. CCH and SGH fish sampled in July and August could not be separated into early, mid, or late release groups by thermal marks. Fish from WNH were separated by release date, and only WNH early release are shown.

CCH= Cannery Creek Hatchery
SGH = Solomon Gulch Hatchery; weights from Alaska Department of Fish and Game (personal communication).
WNH early = Wally Noerenberg Hatchery early release
N1 and N2 = stations in northeast PWS taken in July, 1998
C1 and C2 = stations in central PWS taken in July, 1998
S1 and S2 = stations in southwest PWS taken in July, 1998
CP2 = station in GOA taken in August, 1998
GP = station in GOA taken in August, 1998

Cohort	Station	Early	Mid	Late	N1	N2	C1	C2	S1	S2	CP2	GP
CCH	Wet weight (g)	0.178		0.264	6.798	8.191	6.074	6.430	4.734	8.436	13.219	
	n	50		21	6	7	38	17	12	4	8	
	se	0.007		0.015	0.500	0.437	0.286	0.264	0.389	0.984	0.491	
SGH	Wet weight (g)	0.42	0.52	0.72			10.054			14.632		23.11
	n						8			5		4
	se						0.55201			0.72195		1.693
WNH	Wet weight (g)	0.413					8.287	8.117		11.510	13.310	
early	n	50					7	9		6	4	
	se	0.014					0.763	0.399		0.872	1.258	

Table A-1.5. Average energy content of juvenile pink salmon sampled at different times and locations during their first six months at sea.

Project	Area	Date	Station	Event/Gear	Average condition (cal/g dry weight)	n	Standard deviation	Standard error
PWSAC	PWS	May 8	AFKearly		4,978.405	10	267.752	84.671
		May 24	AFKlate		4,974.643	10	240.716	76.121
		May 7	CCHearly		5,541.881	10	126.981	40.155
		May 29	CCHlate		5,206.232	10	129.126	40.833
		May 1	WNHearly		5,262.121	10	136.723	43.236
GLOBEC	GOA	July 15	GAK 1i	30-1G				
		July 14	GAK 2	27-1G				
		July 7	GAK 2i	3-1G	4,845.259	10	65.342	20.663
APEX	PWS	July 15	N1	13-1U	4,477.728	10	88.107	27.862
		July 15	N2	16-1U	4,779.678	10	99.096	31.337
		July 16	C1	29-1U	4,370.035	30	120.954	22.083
		July 17	C2	35-1U	4,555.569	29	114.100	21.188
		July 18	S1	50-1U	4,502.854	11	99.763	30.080
		July 19	S2	65-1U	4,601.304	9	55.464	18.488
OCC	GOA	August 3	CD1	105	4,852.335	16	79.369	19.842
		August 3	CD2	104	4,914.422	11	66.191	19.957
		August 1	CP1	98	4,776.456	14	85.752	22.918
		August 1	CP2	97	4,857.911	30	68.939	12.586
		August 2	GP	101	4,756.605	15	67.491	17.426
GLOBEC	GOA	October 4	GAK 1	4-1G	4,699.842	5	78.155	34.952
		October 8	GAK 2	10-1G	4,466.229	6	95.878	39.142
		October 8	GAK 4	9-1G	4,725.288	8	97.547	34.488
		October 8	GAK 5	8-1G	4,793.721	12	141.390	40.816
		October 6	GAK 6	6-1G	4,662.433	10	192.478	60.867

Table A-1.6. Average energy content, sample sizes (n), and standard errors (se) of pink salmon from three hatchery groups. Energy content of fish sampled at time of release are shown for early, mid, and late released fish. Pink salmon sampled in July (PWS) and in August (GOA) were separted by their thermal marks and measured. CCH and SGH fish sampled in July and August could not be separated into early, mid, or late release groups by thermal marks. Fish from WNH were separated by release date, and only WNH early release are shown.

CCH= Cannery Creek Hatchery
SGH = Solomon Gulch Hatchery
WNH early = Wally Noerenberg Hatchery early release
N1 and N2 = stations in northeast PWS taken in July, 1998
C1 and C2 = stations in central PWS taken in July, 1998
S1 and S2 = stations in southwest PWS taken in July, 1998
CP2 = station in GOA taken in August, 1998
GP = station in GOA taken in August, 1998

Cohort	Station	Early	Mid	Late	N1	N2	C1	C2	S1	S2	CP2	GP
CCH	Energy content (cal/g dry weight)	5,541.9		5,206.2	4,487.3	4,791.4	4,400.8	4,575.7	4,466.6	4,601.2	4,877.9	
	n	10		10	5	3	5	5	6	4	8	
	se	40.2		40.8	42.1	83.3	25.2	26.9	40.1	18.0	30.0	
SGH	Energy content (cal/g dry weight)						4,305.7			4,545.1		4,787.3
	n						8			1		4
	se						51.8					42.6
WNH	Energy content (cal/g dry weight)	5,262.1					4,406.9	4,575.0			4,862.3	
early	n	10					6	9			4	
	se	43.2					56.2	41.1			38.5	

Table A-1.7. Average percent dry weights of juvenile pink salmon sampled at different times and locations during their first six months at sea.

Project	Area	Date	Station	Event/Gear	Average percent dry weight	n	Standard deviation	Standard error
PWSAC	PWS	May 8	AFKearly		0.178	50	0.014	0.002
		May 24	AFKlate		0.187	47	0.013	0.002
		May 7	CCHearly		0.182	50	0.018	0.003
		May 29	CCHlate		0.200	21	0.012	0.003
		May 1	WNHearly		0.180	50	0.011	0.002
GLOBEC	GOA	July 15	GAK 1i	30-1G	0.206	6	0.004	0.002
		July 14	GAK 2	27-1G	0.206	2	0.007	0.005
		July 7 + 14	GAK 2i	3-1G + 26-1G	0.215	13	0.010	0.003
APEX	PWS	July 15	N1	13-1U	0.200	25	0.004	0.001
		July 15	N2	16-1U	0.207	25	0.005	0.001
		July 16	C1	29-1U	0.202	105	0.011	0.001
		July 17	C2	35-1U	0.203	61	0.008	0.001
		July 18	S1	50-1U	0.205	25	0.006	0.001
		July 19	S2	65-1U	0.208	25	0.005	0.001
OCC	GOA	August 3	CD1	105	0.222	50	0.006	0.001
		August 3	CD2	104	0.219	50	0.005	0.001
		August 1	CP1	98	0.216	50	0.006	0.001
		August 1	CP2	97	0.215	50	0.006	0.001
		August 2	GP	101	0.219	50	0.008	0.001
GLOBEC	GOA	October 4	GAK 1	4-1G	0.216	5	0.008	0.003
		October 8	GAK 2	10-1G	0.211	6	0.005	0.002
		October 8	GAK 4	9-1G	0.221	8	0.011	0.004
		October 8	GAK 5	8-1G	0.221	12	0.009	0.002
		October 6	GAK 6	6-1G	0.224	10	0.006	0.002

Table A-1.8. Average percent dry weights, sample sizes (n), and standard errors (se) of pink salmon from three hatchery groups. Percent weights of fish sampled at time of release are shown for early, mid, and late released fish. Pink salmon sampled in July (PWS) and in August (GOA) were separted by their thermal marks and measured. CCH and SGH fish sampled in July and August could not be separated into early, mid, or late release groups by thermal marks. Fish from WNH were separated by release date, and only WNH early release are shown.

CCH= Cannery Creek Hatchery
SGH = Solomon Gulch Hatchery
WNH early = Wally Noerenberg Hatchery early release
N1 and N2 = stations in northeast PWS taken in July, 1998
C1 and C2 = stations in central PWS taken in July, 1998
S1 and S2 = stations in southwest PWS taken in July, 1998
CP2 = station in GOA taken in August, 1998
GP = station in GOA taken in August, 1998

Cohort	Station	Early	Mid	Late	N1	N2	C1	C2	S1	S2	CP2	GP
CCH	Percent dry weight	0.182		0.200	0.201	0.207	0.203	0.204	0.205	0.205	0.216	
	n	50		21	6	7	38	17	12	4	8	
	se	0.003		0.003	0.001	0.003	0.001	0.001	0.002	0.000	0.002	
SGH	Percent dry weight						0.207			0.211		0.220
	n						8			5		4
	se						0.003			0.002		0.003
WNH	Percent dry weight	0.180					0.202	0.203		0.208	0.211	
early	n	50					7	9		6	4	
	se	0.002					0.002	0.002		0.001	0.002	

Chapter 2

Diet of juvenile pink salmon in Prince William Sound and the North Gulf of Alaska[2]

Abstract

Fish survival is often determined early in life and can be affected by diet and prey availability. Geographic and seasonal changes in juvenile pink salmon diets were described for their first six months of ocean residence in Prince William Sound and the Gulf of Alaska. Pink salmon diets were compared to the plankton community in July in PWS and the GOA. The diets of pink salmon varied among stations within each sampling period. Geographic variation in pink salmon diet may have implications for their growth. There was a trend of increasing prey sizes consumed over the four sampling periods. Pink salmon in PWS (July) generally consumed small prey items, such as gastropods, cladocerans, small calanoid copepods, and bivalves along with some large prey items, large calanoid copepods and larvaceans. In August, juvenile pink salmon sampled in the GOA were consuming fewer small prey items and most of their prey biomass consisted of pteropods (*Limacina* sp.), larvaceans, hyperiid amphipods, and euphausiids. Prey items consumed by fish sampled in October were larger. The prey items that comprised the largest biomass were large pteropods (*Clio* sp.), large hyperiid amphipods, euphausiids, crab megalopae, and fish.

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Introduction

Fish survival is often determined early in life and can be affected by diet and prey availability (Miller et al. 1990; Healey 1991). Consumption of high-energy prey items affects fish growth and condition positively. Variability in the abundance and availability of high-energy prey items or appropriately sized prey items may be important determinants of zooplanktivorous fish growth and survival.

Zooplankton abundance and community structure can be affected by numerous biological and physical factors. Zooplankton abundance in the North Pacific has been related to water column stability (Gargett 1997; L. Haldorson, Univerity of Alaska Fairbanks, personal communication). Intensification of the Aleutian Low results in increased precipitation, and hence water column stability, in coastal North Pacific waters (Gargett 1997). Increased water column stability in the North Pacific maintains phytoplankton in the euphotic zone and results in increased primary production (Gargett 1997). The increase in primary production may positively affect zooplankton and fish production.

Seasonal variation in zooplankton abundance and composition also occurs in the North Pacific Ocean (Harrison et al. 1983). The peak settled volume of zooplankton in Prince William Sound (PWS) occurs in May to June (Cooney et al. 1995). In spring (March-May), Ekman transport can move oceanic species shoreward and the zooplankton composition in PWS is dominated by large oceanic calanoid copepod species, such as *Neocalanus cristatus*, *N. plumchrus*, and *Eucalanus bungii*, as well as small *Pseudocalanus* spp. copepods and pteropods (Cooney 1993). Some Neocalanus species may be resident in West PWS (K. Coyle, University of Alaska Fairbanks, personal communication). The composition of zooplankton changes again in May, after which it consists of primarily neritic species, such as the large calanoid copepod *Calanus marshallae*, several species of small calanoid copepods, cladocerans, and larvaceans.

Pink salmon are planktivores that depend on zooplankton during their early life history. Over 600 million hatchery pink salmon fry, along with wild fry, are released annually into PWS and it is therefore important to understand the processes that affect their growth and survival. Pink salmon enter PWS as juveniles in late April to May and remain there for up to four months (Cooney 1993). During their residence in PWS, they are exposed to seasonal and geographic variations in zooplankton density and composition (Cooney 1993).

The objectives of this study were to describe the food resources utilized by juvenile pink salmon in their first six months at sea, determine if diet varied among areas and seasons, and if these differences related to growth and condition. To accomplish this objective, I analyzed the diets of the pink salmon sampled on four occasions in 1998 from July to October. Another objective was to examine the portion of the zooplankton community that pink salmon utilize. To accomplish this objective I qualitatively compared the diet of pink salmon to the plankton community in July in PWS and the GOA.

Materials and Methods

Samples of the 1997 brood year of juvenile pink salmon were collected and processed as described in Chapter 1 (Table 2.1 and Figure 2.1). Diet analyses were conducted on fish sampled in the field and not on the fish sampled upon release from hatcheries because those fish would not have begun to consume the zooplankton available in PWS. In the laboratory, frozen fish were thawed, blotted dry, measured, and weighed. The stomach of each frozen fish was extracted and the contents removed. Stomach contents were fixed in 10% formalin and then transferred to 70% isopropanol. Stomachs of formalin-preserved fish were removed and stored in 50% isopropanol for at least 10 days before being examined.

Prey items were counted and identified to a general taxonomic category (Table 2.2). In cases where the prey were too numerous to count, large or rare prey were removed and a Folsom plankton splitter was used to subsample the rest of the contents to a reasonable concentration (approximately 200 prey items). Once the subsampled prey items were counted and identified, the numbers were extrapolated to the original concentration and added to the prey that were not diluted.

Prey numbers

The average number of each prey item ($\bar{n}_i$) in fish stomachs was determined by dividing the total number of a prey species found in all fish at a station by the number of fish sampled at that station (m). The average proportion of numbers of prey items ($\bar{p}_{if}$) was calculated by dividing the number of prey in a prey category by the total number of prey eaten by that fish (f). This was done for all prey categories and all fish sampled at a station. Then the proportions in each prey category were averaged over all the fish sampled at that station to determine the average proportion of numbers of prey items ($\bar{p}_i$): Let n_{if} = the number of prey of category i for the f th fish

i=1, ...n; f=1,..., m

Then ,

$$\bar{n}_i = \sum_f n_{if} / m$$

$$\bar{p}_{if} = \frac{n_{if}}{\sum_i n_{if}}$$

$$\bar{p}_i = \frac{\sum_f p_{if}}{m}.$$

Fish with empty stomachs were not included in the averages. When the average proportion number of a prey item was less than 5% for fish sampled at all stations, it was grouped with the "other" category. The diets of pink salmon sampled in PWS in July were listed in more detail than the diets of other fish, so comparisons could be made to plankton samples (Tables A-2.11 to 2.17).

Prey biomass

The average biomass of each prey item in fish stomachs was determined by dividing the total biomass of a prey species found in all fish at a station by the number of fish sampled at that station. The average proportion biomass of prey items was calculated in the same manner as average percent numbers. Prey weights were obtained from unpublished studies (K. Coyle, University of Alaska Fairbanks, personal communication) and from laboratory measurements (Table 2.2). The biomass of unidentified prey items could not be calculated, therefore they were not included in biomass estimates. Fish with empty stomachs were not included in the averages. Prey categories that comprised less than five percent of the diet (by numbers or biomass) for all stations were combined into an "other" category.

Prey Size

The average weight of an individual prey item consumed by juvenile pink salmon was calculated. The total biomass of all identifiable prey items was divided by the total number of identifiable prey items found in the stomachs of each fish; these were averaged at each station. Average individual prey weights (PW) at each station were regressed against the average fork lengths (FL) of fish at each station:

$PW = b + m(FL)$, where

PW = average individual prey weight (mg)

m = slope of the regression line

FL = fork length (mm)

b = intercept of the regression line.

Plankton Samples

Zooplankton was collected at night in the GOA at stations within 20 km of stations where fish were sampled along the Seward hydrographic transect in July. A 1 m^2

multiple opening and closing net (MOCNESS) was used to estimate zooplankton density from 60 m to the surface and from 20 m to the surface. Zooplankton data was provided by K. Coyle (University of Alaska Fairbanks, personal communication).

Plankton was sampled with bongo nets (243 um mesh, 0.2 m diameter) at night from 60m depth to the surface at the same stations where fish were sampled in PWS (J. Purcell, University of Maryland, personal communication, Table 2.3). Nets were equipped with flowmeters so that the density of prey items per meter squared of surface could be calculated. Plankton species were preserved in 5% buffered formalin for laboratory analyses. The samples were split with a Folsom splitter and sorted to major prey categories (J. Purcell, University of Maryland, personal communication, Table 2.4). The percent numbers of prey items were averaged over the 8 stations in the northeast and southwest areas of PWS. L. Haldorson (University of Alaska Fairbanks, personal communication) found that the samples taken in central PWS were different between the west and east side of Naked Island; therefore, four samples were averaged for the central west area and four samples were averaged for the central east area. Area-wide averages were utilized rather than examining individual stations because plankton was not sampled at the exact same time as the fish.

Results

Diet

Important prey items of juvenile pink salmon during their first six months at sea included calanoid copepods, larvaceans, euphausiids, cladocerans, pteropods, and hyperiid amphipods. The types of prey consumed varied geographically with no apparent pattern. Pink salmon consumed progressively larger prey items as they grew from July to October.

GOA -July

Pink salmon diets in the GOA in July varied among stations. Fish at GAK1i consumed primarily large calanoid copepods and larvaceans in both proportions of numbers and biomass (Figure 2.2, Tables A-2.1 and A-2.2). The two fish sampled at GAK2 consumed euphausiids (51.6%) and cladocerans (13.1%). Since euphausiids are much larger than cladocerans, they dominated the biomass of the diets at GAK2. Fish sampled at GAK2i consumed mainly cladocerans (34.2%), gastropods (27.8%) and large calanoid copepods (9.9%) in proportions of numbers. Euphausiids (13.3%) and larvaceans (14.8%) were also important in terms of biomass proportions.

PWS -July

The diets of pink salmon in PWS in July also varied among stations. Cladocerans were consumed by pink salmon at all stations and they represented the majority of prey numbers consumed by fish at N1 (85.2%) and S1 (54.0%) (Figure 2.3, Tables A-2.3 and A-2.4). Bivalves were consumed in small numbers (3-16%) by fish at all stations. Barnacle nauplii represented very small proportions of fish diets at all stations except C1, where they comprised 14% of the fish diets. Small calanoid copepods were consumed in small numbers by fish at four stations (N1, N2, C2, S2); however, they comprised 55.7

and 10.7% of the number of prey consumed at C1 and S1, respectively. Fish consumed primarily large calanoid copepods at station N2 (81.1%). Large calanoid copepods were virtually absent in fish stomachs at all other stations except C2, where they represented 17.7% of the fish diet. Larvaceans were only present in fish stomachs sampled in southeast PWS. They were the major prey item of fish at station S2 (77%) and represented 8.7% of the diet at S1. Fish at C2 consumed a large proportion of gastropods (31%) (Figure 2.3, Tables A-2.3 and A-2.4). When numbers of prey were converted to biomass, the patterns in prey use were generally similar. Large-sized prey comprised a larger proportion of the diet than small prey (Figure 2.3, Tables A-2.3 and A-2.4). Small proportions of gastropods, fish, polychaetes, barnacle cyprids, and insects were found in some of the stomachs of fish (Tables A-2.3 to A-2.8).

GOA -August

In August in the GOA, pink salmon diets again varied considerably among stations. Pink salmon at both Cape Puget stations consumed a large number of *Limacina* sp. pteropods, 37.7 and 47.3% at CP1 and CP2, respectively (Figure 2.4, Tables A-2.5 and A-2.6). Other prey items consumed at CP1 include large calanoid copepods (14.6%), euphausiids (4%), gelatinous zooplankton and insects (included in the 'other' category). Besides *Limacina*, fish at CP2 consumed 48.4% larvaceans. Pink salmon at Cape Douglas stations 1 and 2 consumed 28.1 and 49.5% hyperiid amphipods, respectively. Other important prey items at these two stations were gastropods (16.2 and 5.1% at stations 1 and 2, respectively), larvaceans (7.0 and 20.2% at stations 1 and 2, respectively), large calanoid copepods (7.0 and 2.8% at stations 1 and 2, respectively), as well as some crab zoeae (included in the 'other' category). Fish sampled at GP consumed primarily gastropods (59.9%), with some large calanoid copepods (15.9%) and larvaceans (22.5%) (Figure 2.4, Tables A-2.5 and A-2.6). When converted to biomass proportions, the patterns were similar, although gastropods became less important, and euphausiids became more important (Figure 2.4, Table A-2.6).

GOA -October

The diets of fish sampled in October consisted of larger prey items. Hyperiid amphipods, large calanoid copepods, and *Clio* sp. pteropods were numerically important prey at most stations sampled (Figure 2.5, Tables A-2.7 and A-2.8). Hyperiid amphipods comprised the majority of pink salmon diets (number proportions) at GAK station 1 and 2 (45.4 and 62.4%), and were present in the diets of fish sampled at GAK stations 4, 5,and 6 (13.1, 21.5, 7.9%, respectively). Large calanoid copepods were more important in diets of fish at stations further from shore, GAK 4, 5, and 6 (29.9, 13.1, 13.7%), than those closer to shore, GAK 1 and 2 (7.9 and 5.5%). The large pteropod, *Clio* sp., was consumed in large proportions (up to 42.3 in terms of number proportions) at all stations except GAK 1. Crab megalops and euphausiids were also consumed in large proportions by fish at GAK 1 (24.1 and 7.2%). Fish were important prey items for pink salmon at GAK 6 (10.1%) (Figure 2.5, Tables A-2.7 and A-2.8). Crab megalops, fish, euphausiids, and Clio sp. are large prey items, therefore, they were slightly more important in the pink salmon diets in terms of biomass (Figure 2.5 and Table A-2.8).

Prey Size

Pink salmon prey were arranged in order of increasing size, to examine trends in pink salmon diets. There are variations in prey sizes within each prey category; therefore, sizes are arranged in approximate order of size. The smaller prey items that juvenile salmon consume include bivalves, small calanoid copepods (<2.5 mm), gastropods, cladocerans, *Limacina* sp., and nauplii. These prey items are generally less than 0.34 mg in average weight (K. Coyle, University of Alaska Fairbanks, personal communication, Table 2.2). Larger prey items consumed included larvaceans, large calanoid copepods, hyperiid amphipods, crab megalopae, fish, *Clio* sp., and euphausiids. These larger prey items weigh more than 0.39 mg and most weigh well over 1mg on average (K. Coyle, University of Alaska Fairbanks, personal communication, Table 2.2).

There was a trend to increasing sizes of prey items consumed by juvenile pink salmon from July to October (Figures 2.6 and 2.7). The diets of juvenile pink salmon in PWS and the GOA in July consisted primarily of the smaller prey items and some large calanoid copepods. In August, there were fewer of the smallest prey items in the stomachs of pink salmon sampled in the GOA. By October, the diets of pink salmon were dominated by mainly large prey items, such as *Clio* sp. Fish consumed some small prey items (*Limacina* sp. and small calanoid copepods) in October; however, in terms of biomass, these items comprised an insignificant amount of the food consumed (Figures 2.6 and 2.7).

Observations of increasing prey size with increasing fish size were supported by the relationship of average individual prey weight to average fish length (Figure 2.8).

The average weight of individual prey items consumed increased as a function of the average fish length ($R^2 = 0.7$; Figure 2.8). Fish shorter than 150 mm consumed prey less than 3 mg in weight; whereas, longer fish tended to consume larger prey, up to 16mg in weight (Figure 2.8).

Plankton

GOA –July

Zooplankton density at nearshore stations along the Seward hydrographic transect was highest at GAK2 in the upper 20 m (>12,000 animals/m^2, K. Coyle, University of Alaska Fairbanks, personal communication, Figure 2.9). Densities at the other two stations were less than 4,000 animals/m^2 in the upper 20 m of the water column (Figure 2.9). When zooplankton densities were integrated over the upper 60 m depth, densities were about 8,000 animals/m^2 at GAK 1 and 2 and about 4,700 animals/m^2 at GAK3 (K. Coyle, University of Alaska Fairbanks, personal communication). The majority of zooplankton was comprised of large calanoid copepods at most stations and depth intervals. The second most common zooplankton was the pteropod, *Limacina helicina*, which were present in densities ranging from 700 and 2,000 animals/m^2 (K. Coyle, University of Alaska Fairbanks, personal communication, Figure 2.9).

PWS -July

Plankton density was highest in the southwest area of PWS (2.07×10^5/m^2 surface) and second highest in west central PWS (1.47×10^5/m^2 surface) (Figure 2.10 and

Tables A-2.9). The northeast and east central areas had much lower densities of zooplankton, 0.75 and 0.61 x $10^5/m^2$ surface, respectively. Small calanoid copepods comprised the majority of plankton sampled in all areas, representing 48.7-86.0% of the plankton (Figure 2.10, Tables A-2.9 and A-2.10). Cladocerans and veligers comprised between 12.1 and 35.6% of the plankton in all areas, and densities of both were highest in northeast PWS. Large calanoid copepods comprised a very small percentage of the plankton in all areas of PWS (0.02-0.18%) (Figure 2.10, Tables A-2.9 and A-2.10). Pteropods (*Limacina* sp.), fish, barnacle cyprids, insects, and polychaetes were prey items found in fish stomachs, however, they were not sampled with the BONGO nets (Tables A-2.9 to A-2.17).

Diet and Plankton Comparison

GOA -July

The pink salmon diets and plankton samples in the GOA in July look similar at one station, but different at another. The prey items that comprised the largest proportion of juvenile pink salmon diets at GAK1i were large calanoid copepods and larvaceans (Figure 2.11). Large calanoid copepods also represented the majority of the plankton that was sampled in the upper 20 and 60 m of the water column (Figure 2.11). Fish at GAK2i consumed a wide variety of prey, with gastropods and cladocerans representing the majority (Figure 2.12). Large calanoid copepods comprised the majority of zooplankton in the upper 20 and 60 m of the water column (Figure 2.12).

PWS -July

Juvenile pink salmon in PWS consumed prey in proportions that were different from what was available in the environment at most stations (Figures 2.13 - 2.16). Pink salmon diets were typically dominated by one prey group, which represented over 50% of stomach contents. Small calanoid copepods comprised the largest proportion of prey available at all stations as sampled with the BONGO nets; however, only pink salmon at C1 consumed a large proportion of them (56%) (Figure 2.14). Pink salmon diets at N1 were dominated by cladocerans (85%) and at N2 by large calanoid copepods (81%). Cladocerans and large calanoid copepods comprised only 15 and 0.05% of the zooplankton sampled in Northeast PWS, respectively (Figure 2.13). Pink salmon at C2 consumed a wide variety of prey items, with the majority represented by gastropods (31%), which were not sampled with the BONGO nets (Figure 2.15). Fish at S1 consumed primarily cladocerans (54%) and fish at S2 consumed larvaceans (77%), which represented only 2 and 0.3% of the zooplankton, respectively (Figure 2.16). In all cases, except at C1, pink salmon diets were comprised of large-sized prey items that represented only small proportions of the zooplankton. Fish at C1 consumed prey in similar proportions to what was in the environment, in terms of prey size and group (Figure 2.14).

Discussion

The diets of juvenile pink salmon were similar to those found in other studies (Bailey et al. 1975; Cooney et al. 1978; Godin 1981; Healey 1991; Perry et al. 1996).

Major prey items included calanoid copepods, larvaceans, euphausiids, cladocerans, pteropods, other gastropods, and crab megalopae. The importance of these prey items in pink salmon diets, however, varied geographically within each of the time periods sampled. Geographic variation in feeding by juvenile pink and chum salmon has also been found within other areas of the North Pacific (Godin 1981; Perry et al. 1996). Previous studies have attributed variation in fish stomach contents to the time of day the fish were sampled, fish selectivity, prey density, zooplankton community structure, and fish size (Confer et al. 1990; Schael et al. 1991; Perry et al. 1996).

Within each sampling period all fish were captured over 3 to 9 days and during the same time of the day (i.e. either day or night). For example, all fish sampled in PWS and the GOA were caught in the daytime, over 5 to 9 days in July and August. Fish sampled in the GOA in October were sampled at night over 5 days. It is unlikely, therefore, that differences in diet composition among stations within each sampling period was affected by sampling time; however, differences among periods could be due to diel differences in zooplankton availability.

Most sampling was conducted during daylight hours; however, fish sampled in October were sampled at night. Euphausiids and some large calanoid copepods vertically migrate and are found in the surface waters at night, changing the zooplankton composition (Harrison et al. 1983). If fish consumed diel vertically migrating prey during the night, this may have affected the observed diet of fish in October relative to the other sampling periods. Juvenile pink salmon, however, are thought to occupy surface waters and feed primarily during daylight hours (Godin 1981; Moulton 1997).

Observed diets of fish sampled at night may, therefore, be comprised of prey items that were consumed in the day.

Examination of fish stomachs provides an indication of the prey utilized by fish; however, digestion times of prey may hinder estimation of the importance of each prey item. Prey that are large and/or more difficult to digest, such as euphausiids and shelled gastropods, may remain in fish stomachs longer than small and/or soft-bodied prey, such as cladocerans and larvaceans. Analysis of fish stomachs may over-emphasize the presence of prey items that are digested more slowly. For example, if the fish that were sampled at night did not consume prey during the night, all prey items found in their stomachs would have been consumed during the day. Upon examination of these stomachs, the only prey remaining would be those that were difficult to digest.

Geographic variation in zooplankton density may affect the diets of fish in different areas. Water column structure can affect how much zooplankton is available (Gargett 1997; L. Haldorson, University of Alaska Fairbanks, personal communication). Stable ocean conditions maintain phytoplankton in the euphotic zone, resulting in net increased primary production and, hence, secondary production (Gargett 1997). Also, if the water column is more stable, zooplankton may be concentrated in a shallower surface layer; thereby increasing the zooplankton availability to pink salmon. In areas of strong water column stratification, zooplankton can be layered by species (K. Coyle, University of Alaska Fairbanks, personal communication) and this would also change the availability of prey to fish. Plankton density in PWS varied considerably among areas, with the highest densities in the Southwest and West Central PWS (J. Purcell, University of Maryland, personal communication), where the water column was most stratified (L. Haldorson, University of Alaska Fairbanks, personal communication).

Geographic variation in zooplankton community structure may have an effect on pink salmon diets (Harrison et al. 1983; Perry et al. 1996; Sugimoto and Tadokoro 1997; Coyle et al. 1998). In PWS, plankton composition was relatively similar among areas, with small calanoid copepods representing the majority of zooplankton at all stations. There were variations in the composition of other zooplankton groups. For example, the density of large calanoid copepods was highest in West Central PWS ($637/m^2$) and lowest in Northeast PWS ($32/m^2$) (J. Purcell, University of Maryland, personal communication). Large calanoid copepods comprised a large proportion of pink salmon diets at one Northeast station and at the West Central station. This suggests that pink salmon at the northeast station were positively selecting large calanoid copepods, that the large calanoid copepods were more available to fish in northeast PWS, or that the fish in northeast PWS found a patch of zooplankton that was not sampled adequately with the BONGO nets. Other examples from samples taken in PWS show similar disparities between plankton samples and fish diets. For example, cladocerans were relatively dense in NE PWS (12,579/m2) and fish at one station there consumed cladocerans almost exclusively; however, fish at the other NE station did not consume a large proportion of cladocerans (J. Purcell, University of Maryland, personal communication). Small calanoid copepods were dominant zooplankters in all areas, but were only consumed in large proportions at one station (East Central PWS), where zooplankton densities were lowest. Larvaceans were consumed in large numbers only at one station in Southwest

PWS, where the density of larvaceans was lowest. Gastropods were consumed in large numbers at the West Central station, but were not sampled with the BONGO nets. Pink salmon in the GOA consumed bivalves, gastropods, and larvaceans, where there were none sampled by the MOCNESS nets. The disparity between zooplankton density/community structure and the diets of fish, suggest that fish are selective feeders and the type of prey they select varies among stations, zooplankton availability varies among stations, and/or the plankton nets did not sample the zooplankton community utilized by pink salmon effectively.

Fish can feed selectively on zooplankton by consuming specific prey items in higher proportions than they appear in the environment (Monteleone and Peterson 1986; Schmitt 1986; Peterson and Ausubel 1984). Bailey et al. (1975) found that juvenile pink salmon selected cladocerans and larvaceans more frequently than they occurred in the plankton. Purcell and Sturdevant (2001) found that juvenile pink salmon selected larvaceans in PWS. Juvenile sockeye salmon have been found to select large prey items but can switch to smaller prey when large prey are not available (Eggers 1982). Prey selections could be a function of fish size, since there is evidence that larger fish select larger prey (Brooks and Dodson 1965; LeBrasseur 1969; Healey 1991; Schael et al. 1991). A selectivity index could not be calculated in this study because plankton data was only available for PWS and some zooplankton species consumed by fish were not sampled with the BONGO nets in PWS or the MOCNESS nets in the GOA. The plankton samples do, however, provide an indication of the main zooplankton species that the fish may have encountered. Juvenile pink salmon in PWS consumed a wide variety of zooplankton, despite the fact that small calanoid copepods comprised the majority of prey numbers in all areas of PWS. Pink salmon consumed prey items that were larger than small calanoid copepods, such as large calanoid copepods, larvaceans, cladocerans, and gastropods, and they did not consume as many small prey items, such as barnacle nauplii, ostracods, and bivalves (Tables A-2.11 to A-2.16). Pink salmon in the GOA consumed some large calanoid copepods, which dominated the plankton samples; however, they also consumed smaller prey items, such as cladocerans and gastropods.

Plankton distribution is known to be patchy (Mackas et al. 1980; Harrison et al. 1983). There could have been small-scale patches of zooplankton that fish encountered but were not sampled adequately with the plankton nets. The stations sampled were between 10 and 100 km apart, and zooplankton patches may have been smaller than this (Mackas et al. 1980). For example, both fish and plankton could have been concentrated in rip lines and convergences near the surface (Moulton 1997; Hunt et al. 1998). In areas where the water column is stratified, zooplankton may be concentrated in the upper mixed layer; whereas, in areas of weak stratification, zooplankton may be evenly distributed throughout the water column, decreasing the availability of zooplankton to fish. Different zooplankton species can also be found in different layers of the water column in stratified areas (K. Coyle, University of Alaska Fairbanks, personal communication). The BONGO samples were integrated from 60 m depth to the surface; however, it is thought that juvenile pink salmon only occupy the surface waters of PWS (Godin 1981; Moulton 1997). Integration over 60 m of the water column may be inappropriate for determining the zooplankton community structure and density that the juvenile pink salmon experience. The MOCNESS samples were collected about 20 km from the stations where fish were collected and this may have affected the direct comparisons between plankton and fish diets. Plankton and fish sample collections were sometimes separated by up to two days and this could also be a source of variation between fish stomach contents and plankton samples.

The diet of juvenile pink salmon may be reflected in the fish condition (Perry et al. 1996). Due to their larger size and relatively high energy content, large calanoid copepods and larvaceans are potentially the most profitable prey that pink salmon consume, representing approximately 2,300 and 4,900 J per individual, respectively (Cooney et al. 1981; Healey 1991; Davis et al. 1998). In PWS, the juvenile pink salmon that had the highest energy content (N2) consumed the largest proportion of large calanoid copepods (Chapter 1). Fish at the West Central station (C1) consumed primarily small prey items, such as small calanoid copepods, gastropods, cladocerans, and bivalves, and they were in the poorest condition (Chapter 1). There was, however, no apparent relationship between the consumption of large prey and fish condition in the GOA in August or October.

Fish consumption of certain prey species may be related to zooplankton behavior. There is some evidence that the profitability of larger prey items may decline with increasing prey size (Bence and Murdoch 1986). Each species of zooplankton may behave differently, or be able to escape predation with varied levels of success. For example, copepods can dart whereas cladocerans can not; therefore, cladocerans may be easier to capture than copepods. Juvenile sockeye salmon in Lake Washington prefer large, non-evasive cladocerans instead of the more evasive and smaller copepods (Eggers 1982).

The consumption of certain prey items may also be related to the previous experience of the fish and or the detectability of the prey (Checkley 1982; Peterson and Ausubel 1984; Govoni et al. 1986; Northcote 1988). For example, larvaceans may be visible due to their mucous feeding nets (Bailey et al. 1975). Larger prey, in general, may be more detectable than the smaller prey. The pigmentation of these prey items may also make them more detectable by pink salmon (Zaret and Kerfoot 1975). If a fish has previous experience feeding on one type of prey, it may have a tendency to select that prey in the future; therefore, consumption of prey may be determined, in part, by the types of prey that were available in the past.

There was a trend of increasing prey sizes consumed over the four sampling periods. Pink salmon in PWS (July) generally consumed small prey items, such as gastropods, cladocerans, small calanoid copepods, and bivalves along with some large prey items, large calanoid copepods and larvaceans. In August, juvenile pink salmon sampled in the GOA were consuming fewer small prey items and most of their prey biomass consisted of pteropods (*Limacina* sp.), larvaceans, hyperiid amphipods, and euphausiids. Prey items consumed by fish sampled in October were larger. The prey items that comprised the largest biomass were large pteropods (*Clio* sp.), large hyperiid amphipods, euphausiids, crab megalopae, and fish.

Larger fish tend to consume larger prey (Brooks and Dodson 1965; LeBrasseur 1969; Healey 1991; Schael et al. 1991). Brodeur and Pearcy (1990) found that juvenile salmon are not specialists on any one prey item, rather they consume any prey within a specific size range. Gape size increases with fish length and may limit the size of prey a fish can consume (Brooks and Dodson 1965). Healey (1991) found that salmon longer than 130 mm consumed progressively larger prey, and salmon shorter than this consumed prey less than 2 mm in size. In this study, pink salmon shorter than 150 mm consumed prey items weighing less than 3 mg; whereas, fish longer than 150 mm consumed larger prey.

Summary

The diets of pink salmon varied among stations within each sampling period. There was a trend of increasing prey sizes consumed over the four sampling periods. Pink salmon in PWS (July) generally consumed small prey items, such as gastropods, cladocerans, small calanoid copepods, and bivalves along with some large prey items, large calanoid copepods and larvaceans. In August, juvenile pink salmon sampled in the GOA were consuming fewer small prey items and most of their prey biomass consisted of pteropods (*Limacina* sp.), larvaceans, hyperiid amphipods, and euphausiids. Prey items consumed by fish sampled in October were larger. The prey items that comprised the largest biomass were large pteropods (*Clio* sp.), large hyperiid amphipods, euphausiids, crab megalopae, and fish.

Geographic variation in pink salmon diet may have implications for their growth. Fish that find patches of zooplankton with energetically profitable prey items may experience higher growth rates and be in better condition. The condition of pink salmon has been found to vary geographically. Fish condition may, therefore, be related to small-scale processes that concentrate prey. Variation in fish condition may lead to variation in the survival and year class strength of pink salmon from different areas.

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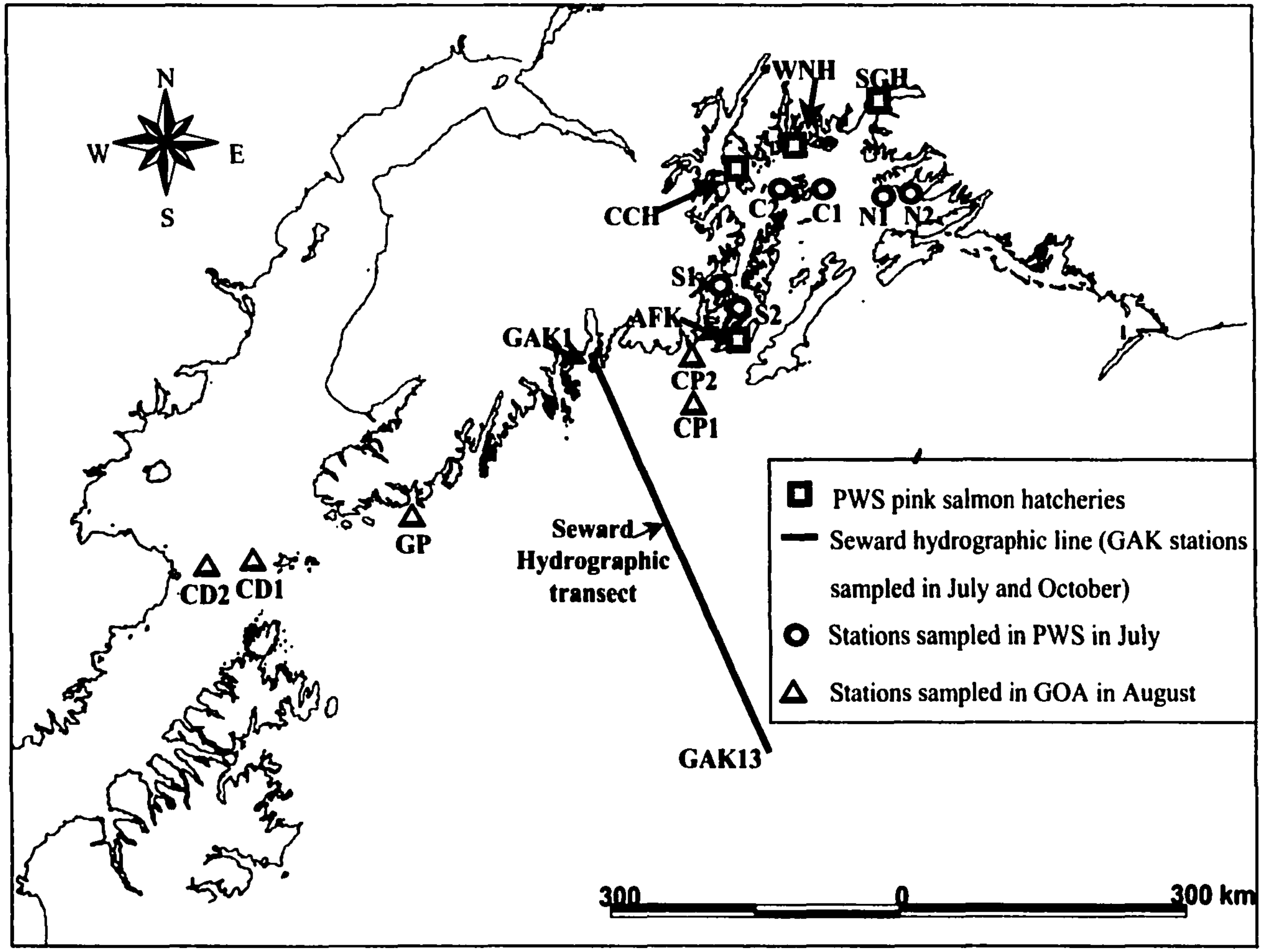

Figure 2.1. Sampling locations in PWS and the GOA in 1998. There are four pink salmon hatcheries in PWS (SGH, WNH, CCH, AFK). Six stations were sampled in PWS in July (N1, N2, C1, C2, S1, S2). Stations along the Seward hydrographic transect were sampled in July and October. Main stations are located every 18.5 km along the Seward transect (intermediate stations, such as GAK1i, are halfway between main stations). Five stations were sampled in the GOA in August (CP1, CP2, GP, CD1, CP2).

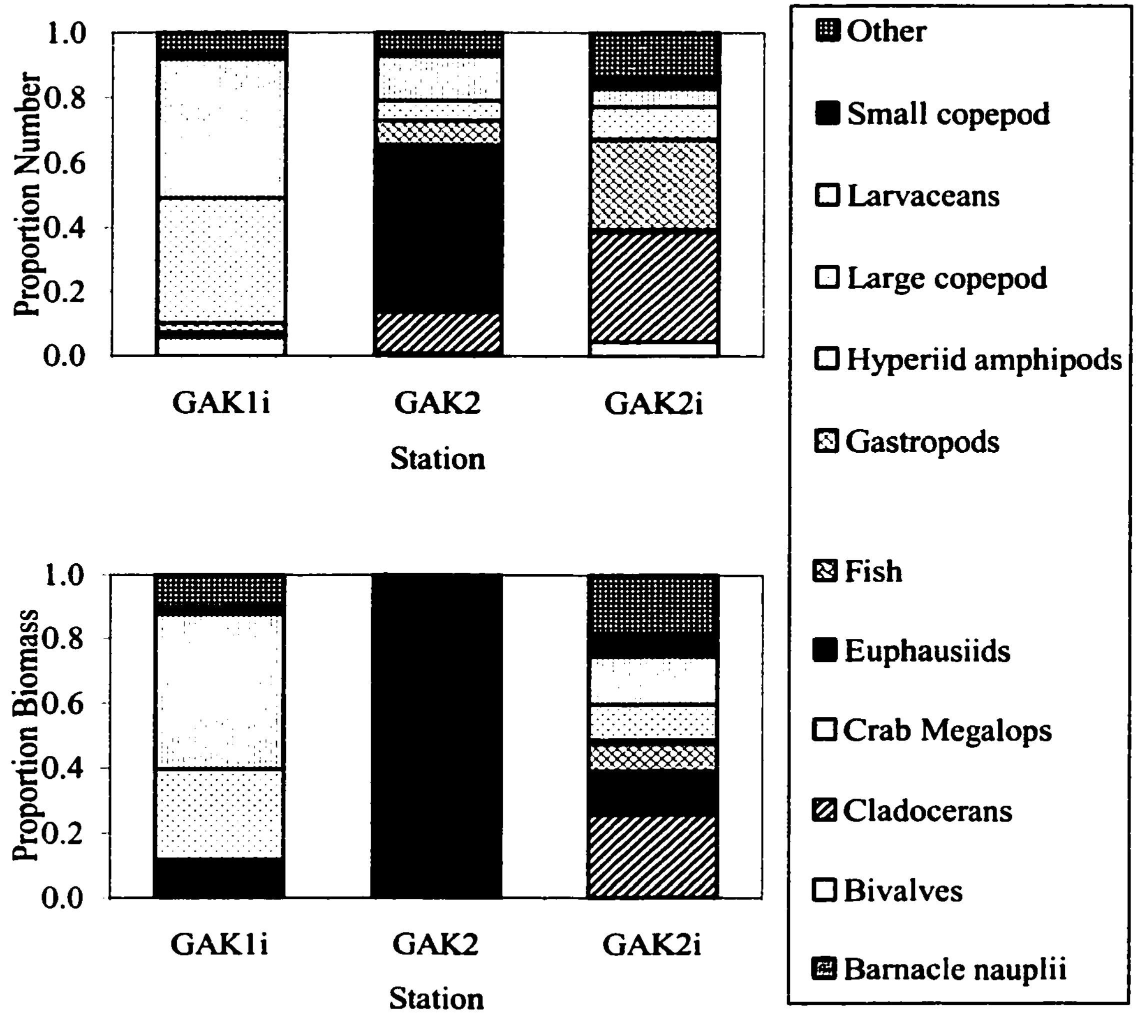

Figure 2.2. Proportions of prey numbers and biomass consumed by juvenile pink salmon in July, 1998. Stations are located along the Seward hydrographic transect in the NGOA.

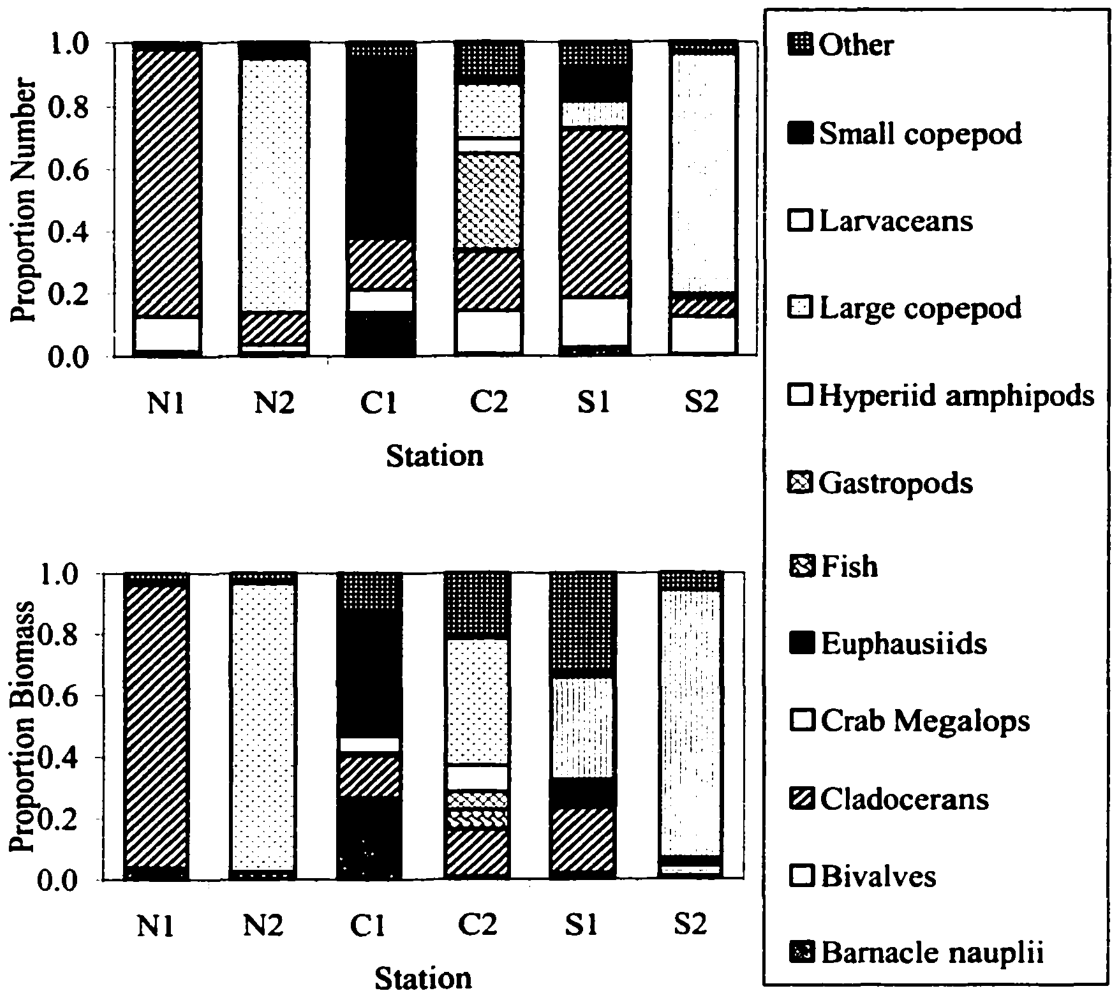

Figure 2.3. Proportions of prey numbers and biomass consumed by juvenile pink salmon in July, 1998. Stations are located in PWS.

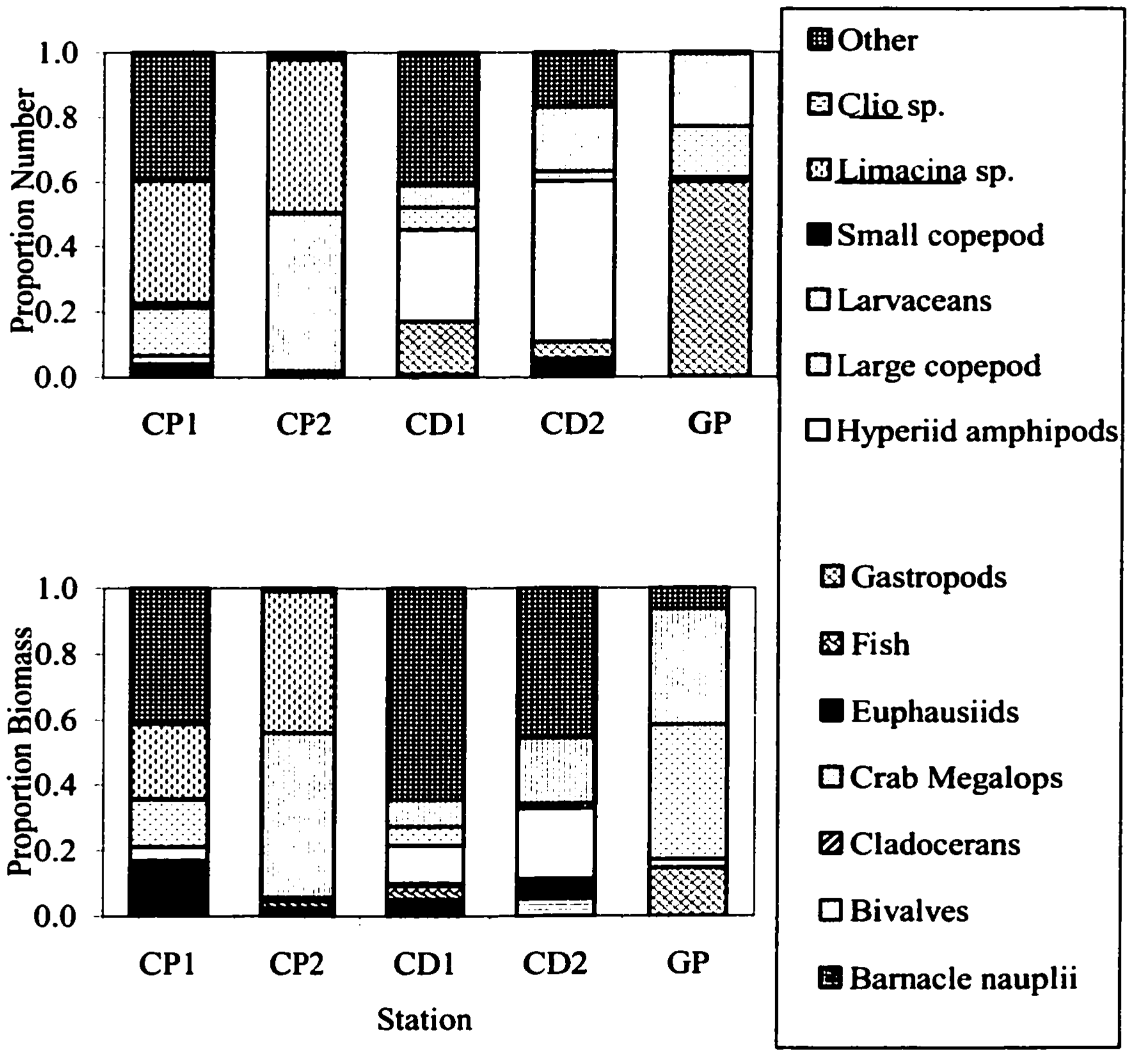

Figure 2.4. Proportions of prey numbers and biomass consumed by juvenile pink salmon in August, 1998. Stations are located in the NGOA.

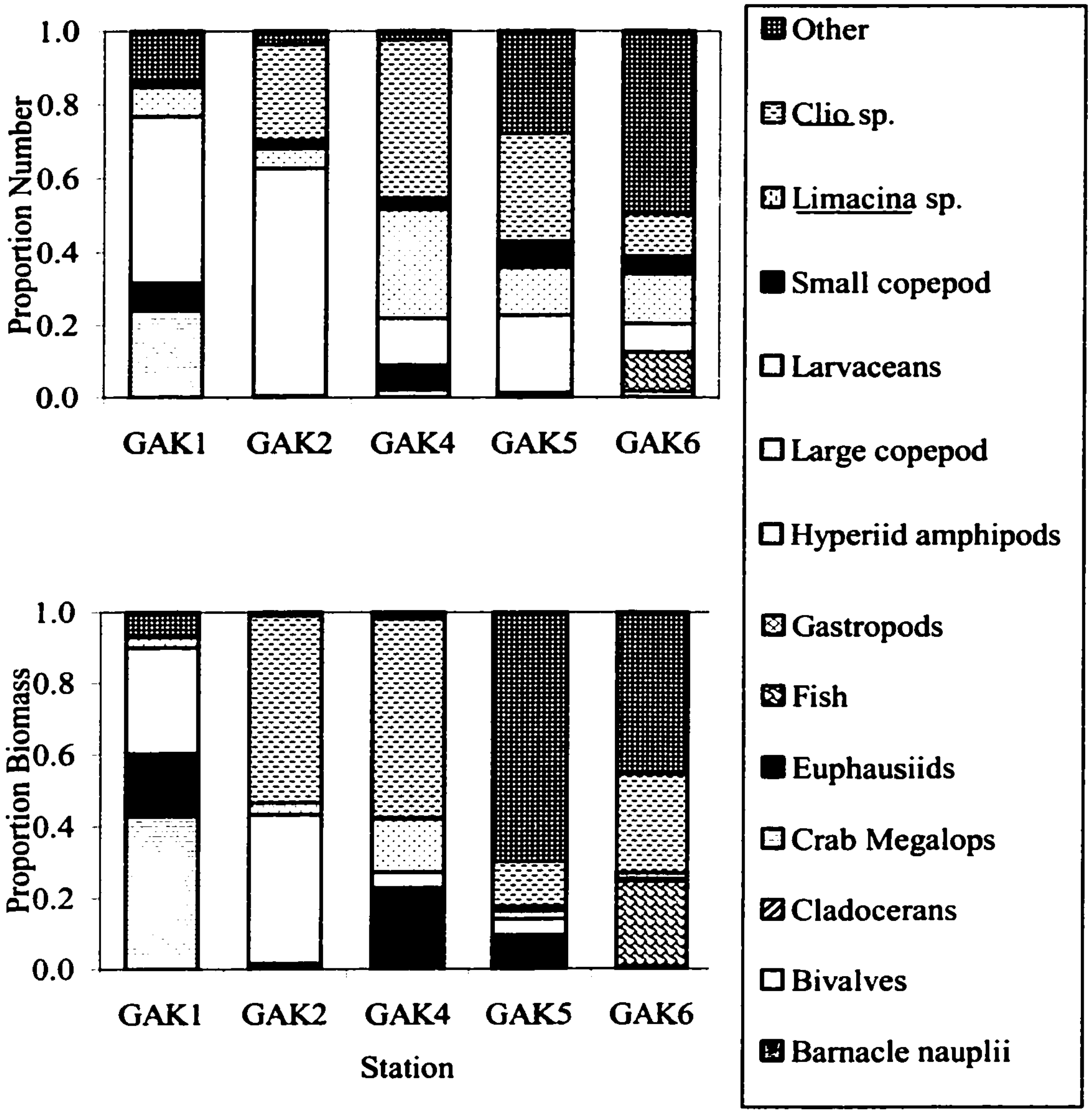

Figure 2.5. Proportions of prey numbers and biomass consumed by juvenile pink salmon in October, 1998. Stations are located along the Seward hydrographic transect in the GOA.

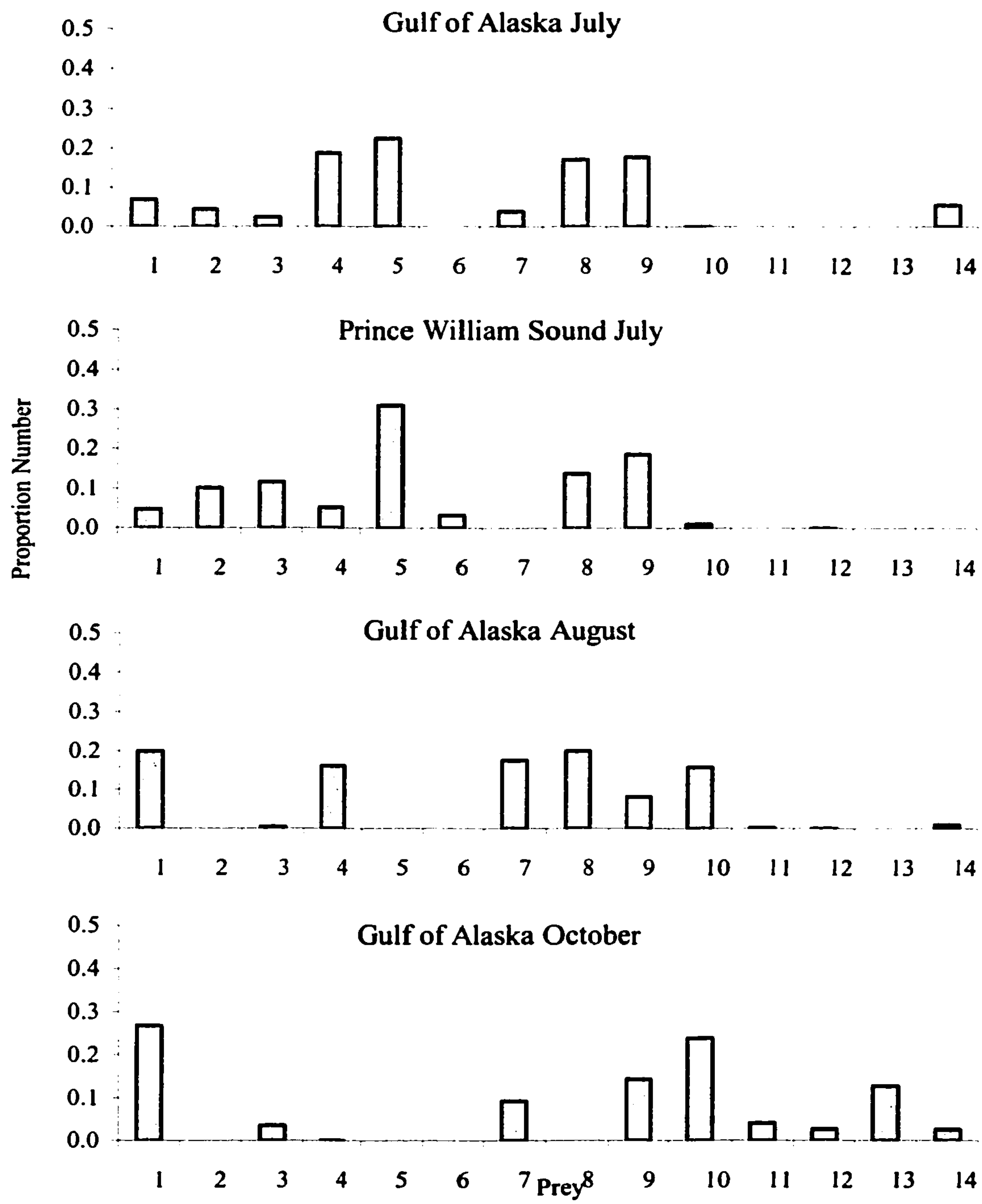

Figure 2.6. Proportions of prey numbers (y-axis) consumed by juvenile pink salmon in four time periods. Prey are arranged from approximately smallest to largest (x-axis). 1.Other, 2.Bivalves, 3.Small copepods, 4.Gastropods, 5.Cladocerans, 6.Barnacle nauplii, 7.*Limacina* sp., 8.Larvaceans, 9. Large copepods, 10.Hyperiid Amphipods, 11.Crab megalopae, 12.Fish, 13.*Clio* sp., 14.Euphausiids.

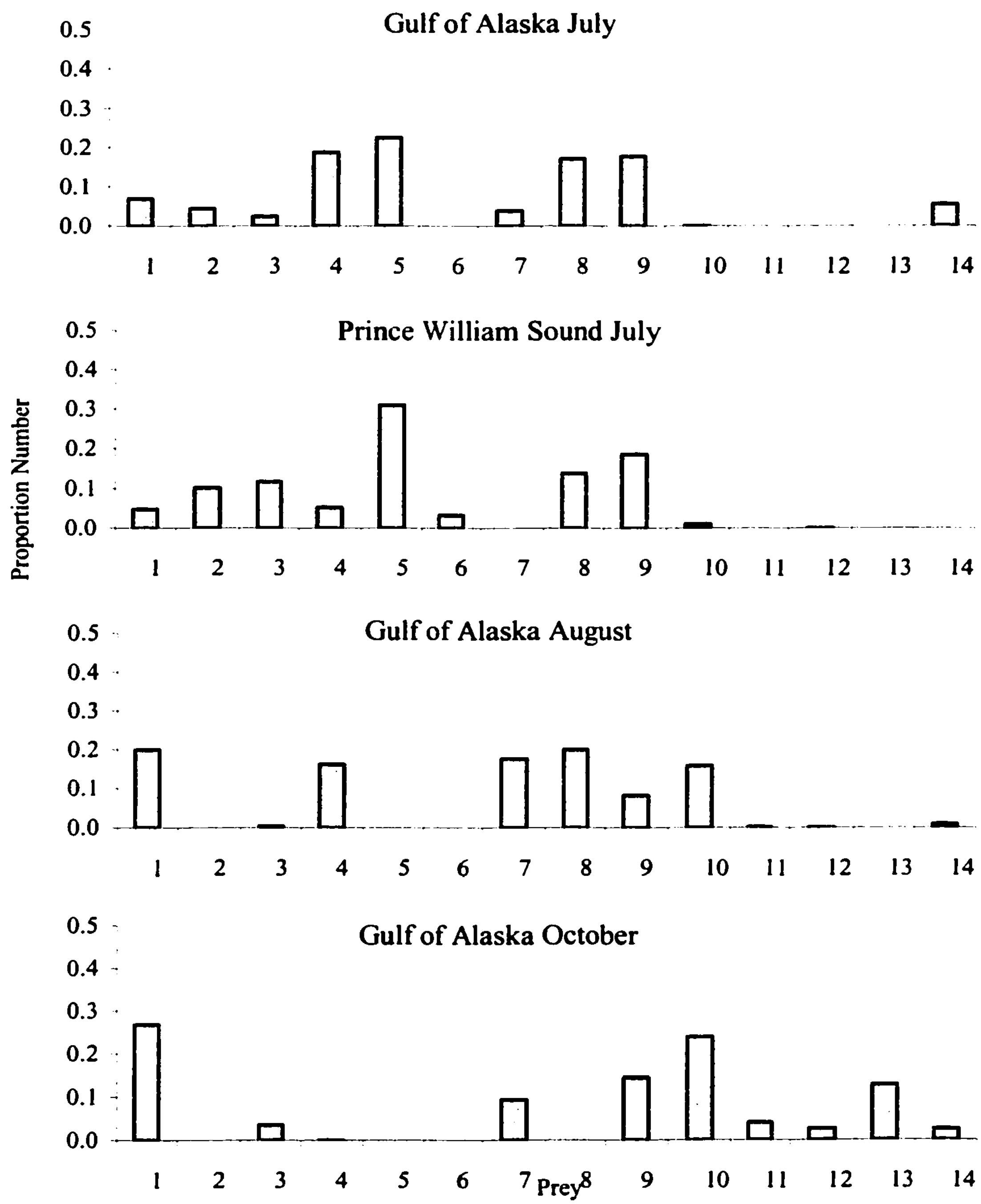

Figure 2.7. Proportions of prey biomass (y-axis) consumed by juvenile pink salmon in four time periods. Prey are arranged from approximately smallest to largest (x-axis). 1.Other, 2.Bivalves, 3.Small copepods, 4.Gastropods, 5.Cladocerans, 6.Barnacle nauplii, 7.*Limacina* sp., 8.Larvaceans, 9. Large copepods, 10.Hyperiid Amphipods, 11.Crab megalopae, 12.Fish, 13.*Clio* sp., 14.Euphausiids.

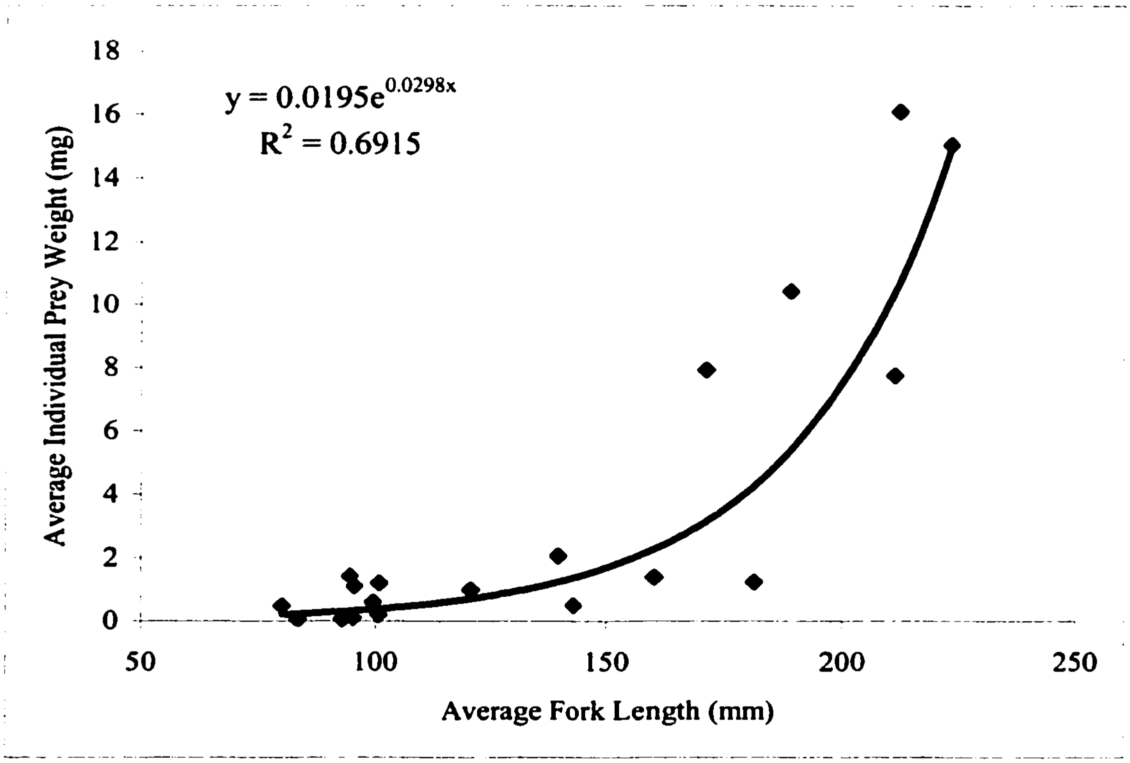

Figure 2.8. Average individual prey weight as a function of average fish fork length at all stations sampled.

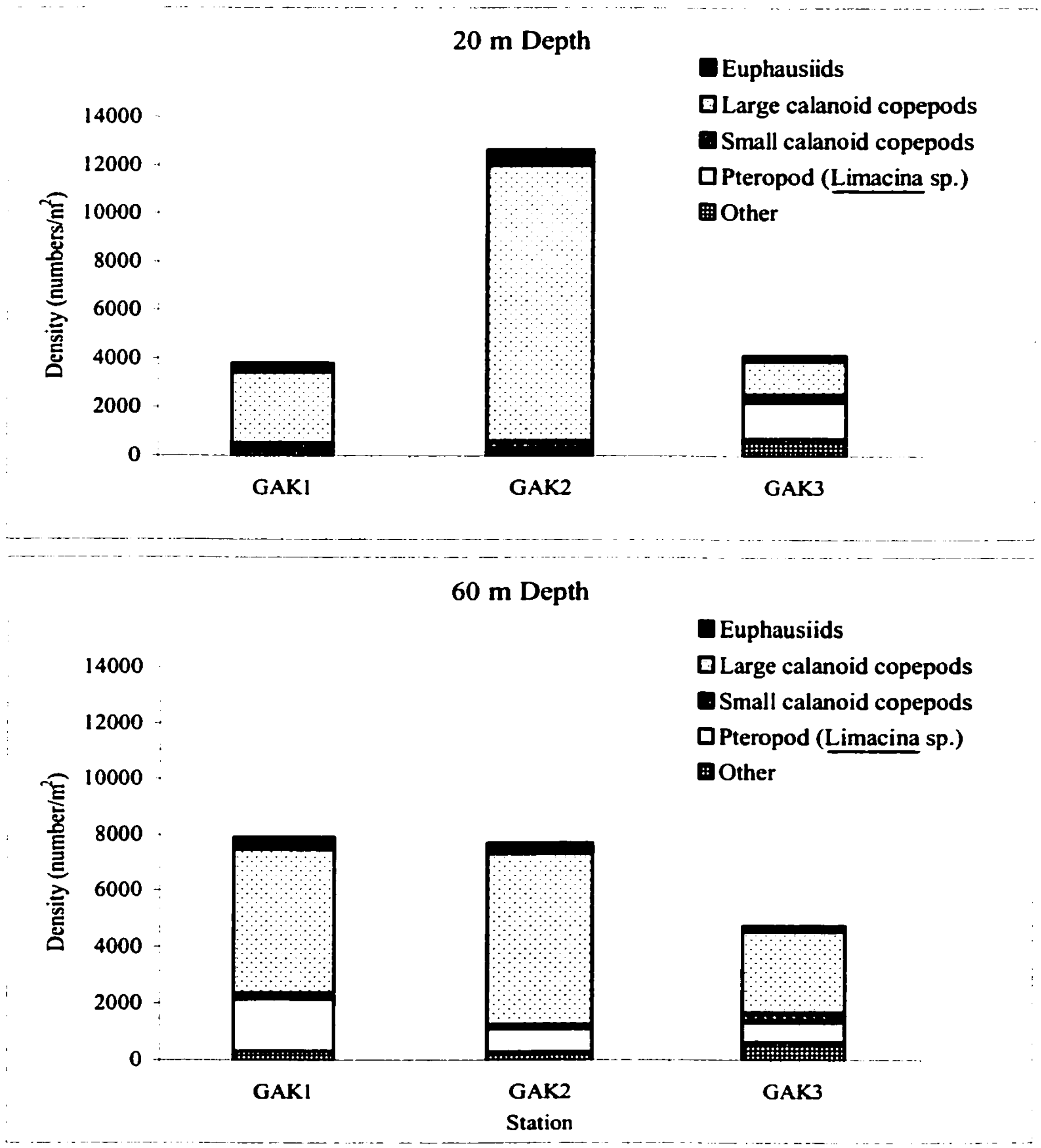

Figure 2.9. Zooplankton density and composition at three nearshore stations along the Seward hydrographic transect. Densities are expressed in numbers per meter squared of surface area from 20 m depth to the surface (top panel) and from 60 m depth to the surface (bottom panel). Data for these graphs were provided from Coyle (personal communication).

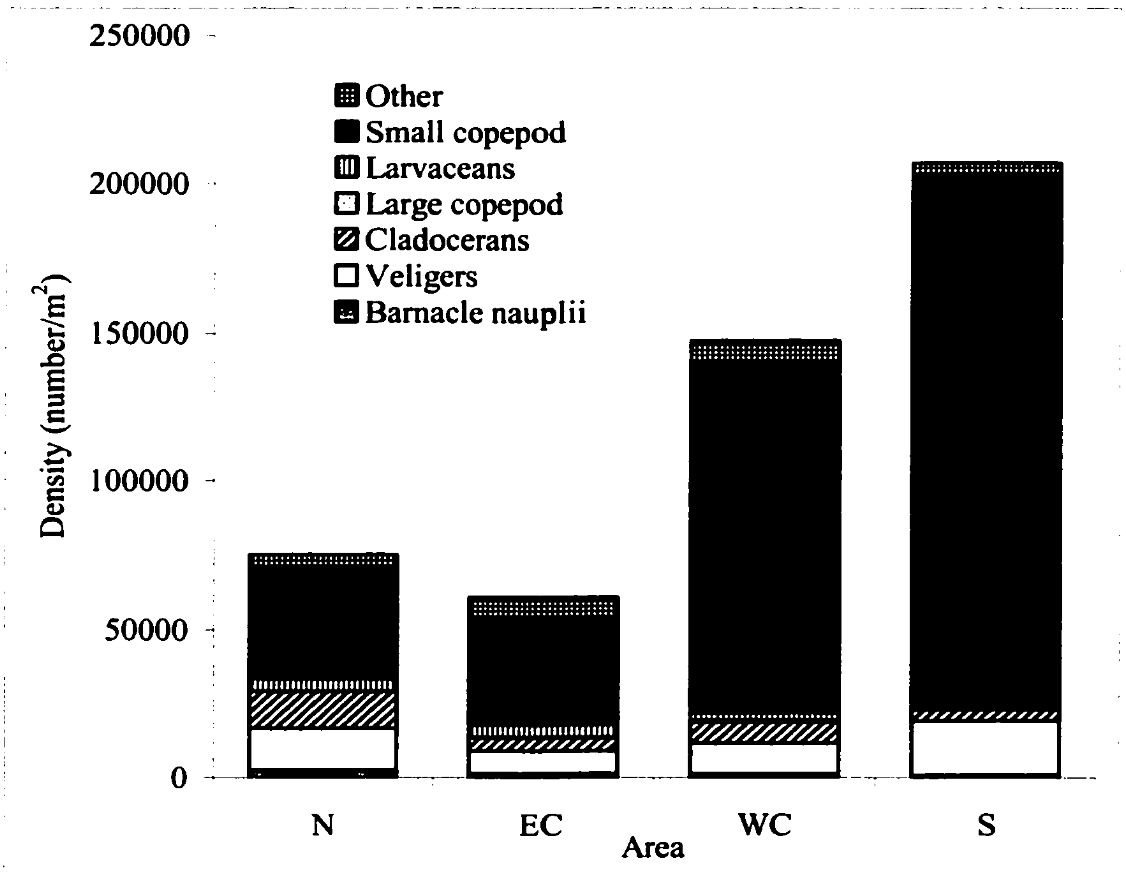

Figure 2.10. Plankton density and composition in the northwestern (N), east central (EC), west central (WC) and southwestern (S) areas of Prince William Sound. Densities are expressed in numbers per meter squared of surface area and are averaged over several stations (eight in N and S areas, 4 in EC and WC areas). Data for this graph were provided from Purcell (personal communication).

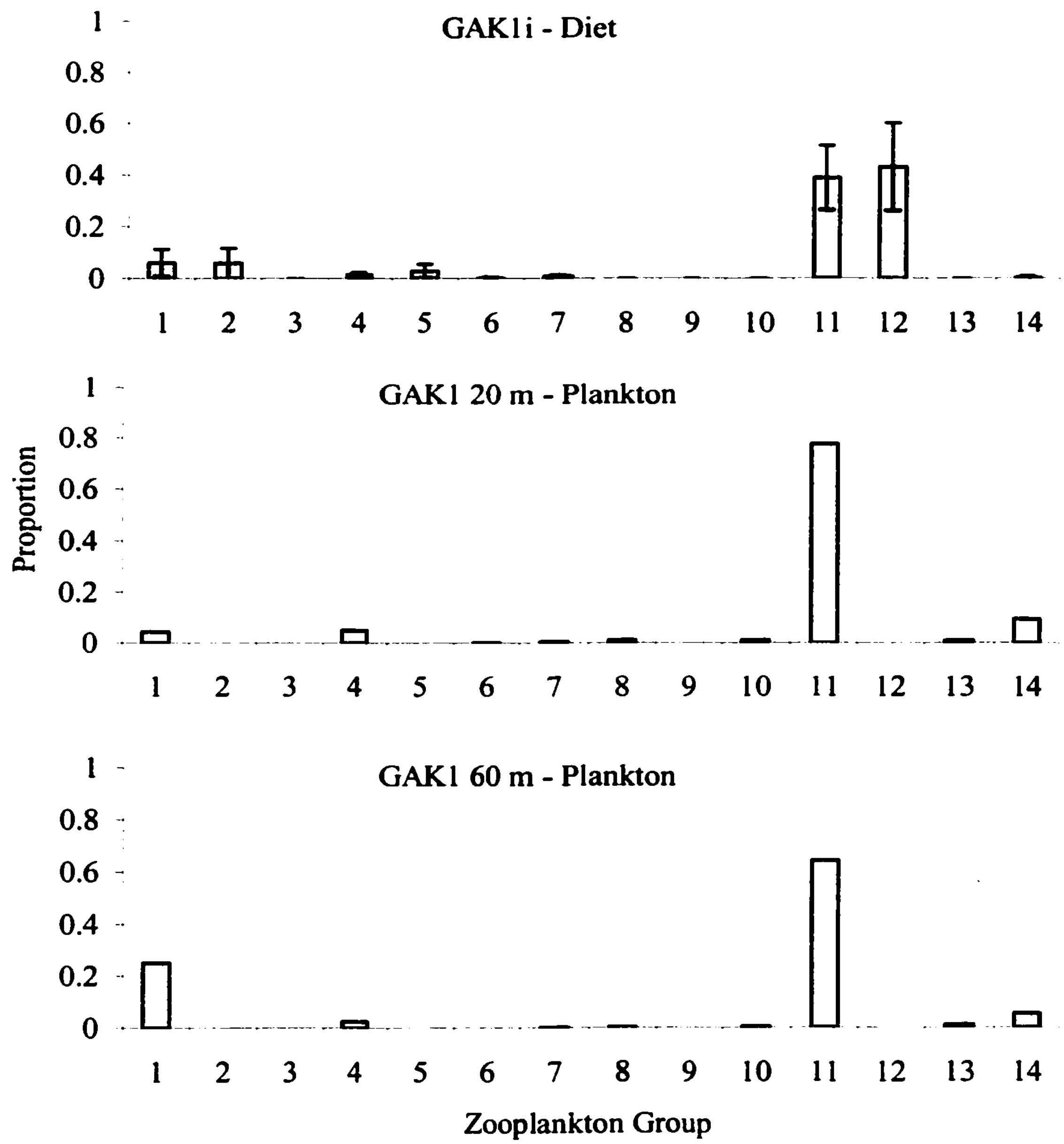

Figure 2.11. Proportions of zooplankton numbers in juvenile pink salmon diets at GAK1i (top panel), in the environment as sampled with MOCNESS nets from 20 m to the surface (middle panel), and from 60 m to the surface (bottom panel) at GAK1 in the N. GOA. Zooplankton groups are arranged in approximate order ofincreasing size on the x-axis. Standard error bars are shown for averages. Zooplankton data provided by Coyle (personal communication). Zooplankton groups: 1. other, 2. Bivalves, 3. Eggs, 4. Small calanoid copepods, 5. Gastropods, 6. Crab zoeae, 7. Cladocerans, 8. Barnacle nauplii, 9. Barnacle cyprids, 10. Amphipods, 11. Large calanoid copepods, 12. Larvaceans, 13. Chaetognaths, 14. Euphausiids.

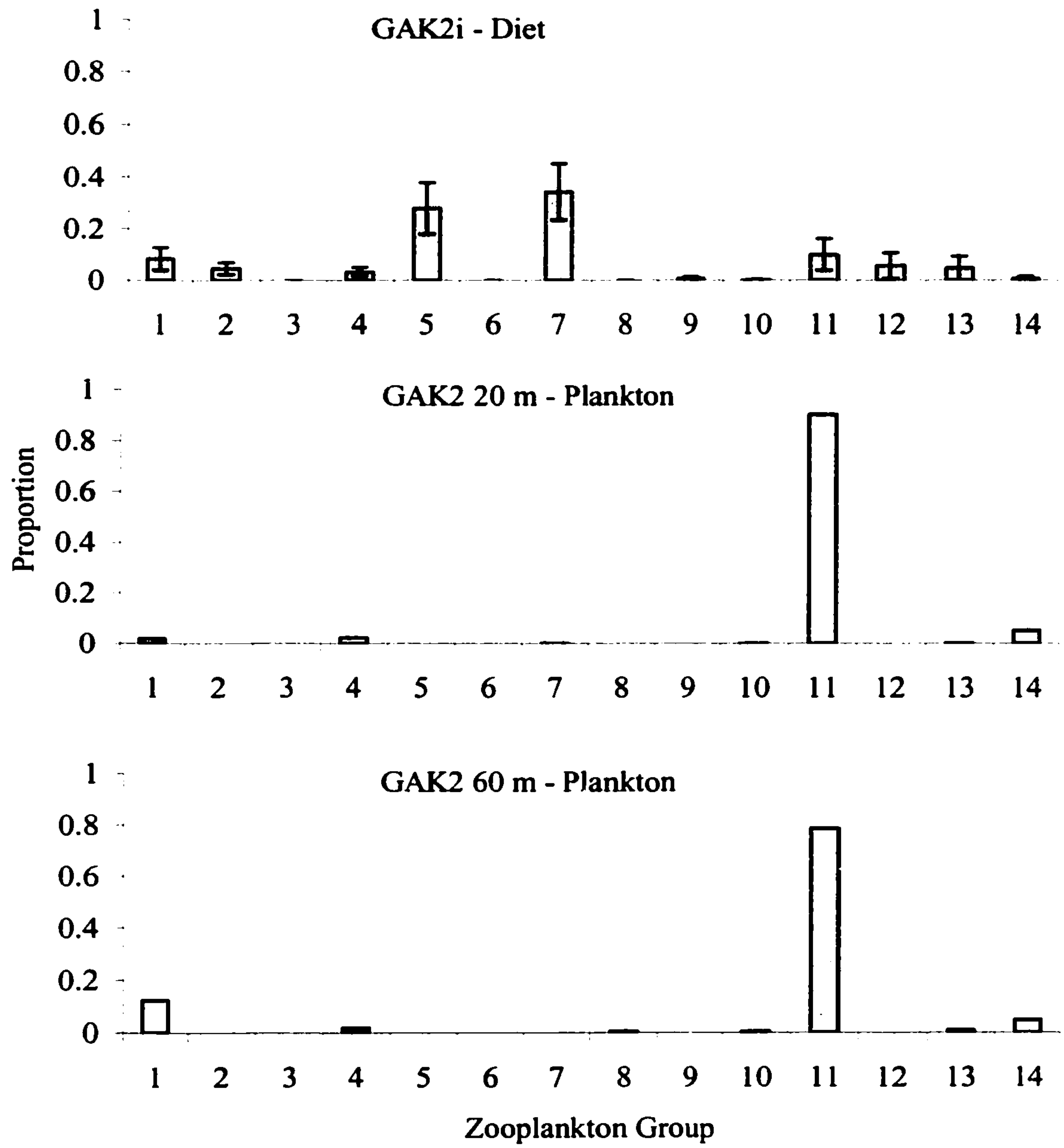

Figure 2.12. Proportions of zooplankton numbers in juvenile pink salmon diets at GAK 2i (top panel), in the environment as sampled with MOCNESS nets from 20 m to the surface (middle panel), and from 60 m to the surface (bottom panel) at GAK2 in the N. GOA. Zooplankton groups are arranged in approximate order of increasing size on the x-axis. Standard error bars are shown for averages. Zooplankton data provided by Coyle (personal communication). Zooplankton groups: 1. other, 2. Bivalves, 3. Eggs, 4. Small calanoid copepods, 5. Gastropods, 6. Crab zoeae, 7. Cladocerans, 8. Barnacle nauplii, 9. Barnacle cyprids, 10. Amphipods, 11. Large calanoid copepods, 12. Larvaceans, 13. Chaetognaths, 14. Euphausiids.

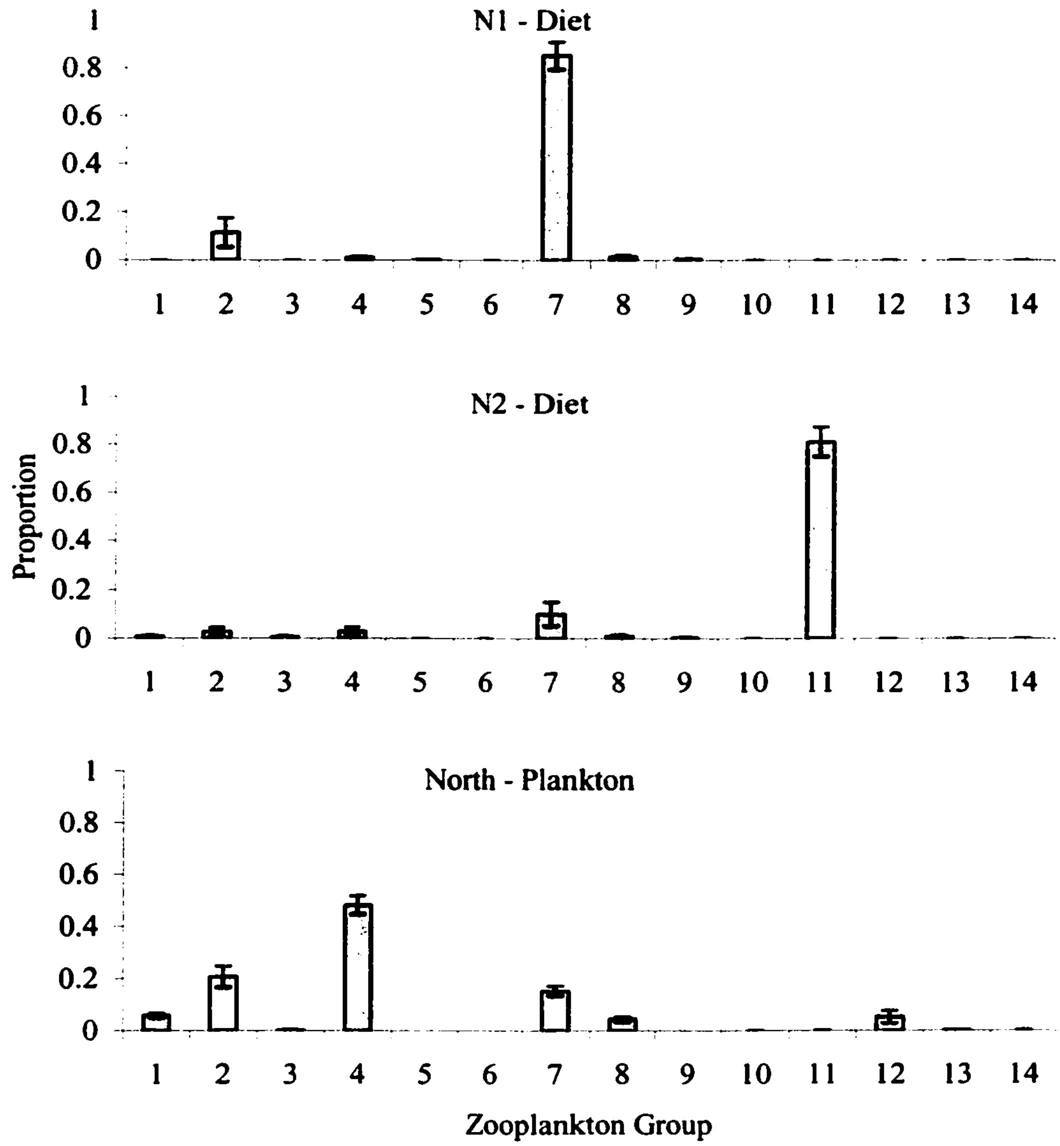

Figure 2.13. Proportions of zooplankton numbers in juvenile pink salmon diets at N1 (top panel) and N2 (middle panel) and in the environment as sampled with BONGO nets (bottom panel) in Northeast PWS. Zooplankton groups are arranged in approximate order of increasing size on the x-axis. Standard error bars are shown. Zooplankton data provided by Purcell (personal communication). Zooplankton groups: 1. other, 2. Bivalves, 3. Eggs, 4. Small calanoid copepods, 5. Gastropods, 6. Crab zoeae, 7. Cladocerans, 8. Barnacle nauplii, 9. Barnacle cyprids, 10. Amphipods, 11. Large calanoid copepods, 12. Larvaceans, 13. Chaetognaths, 14. Euphausiids.

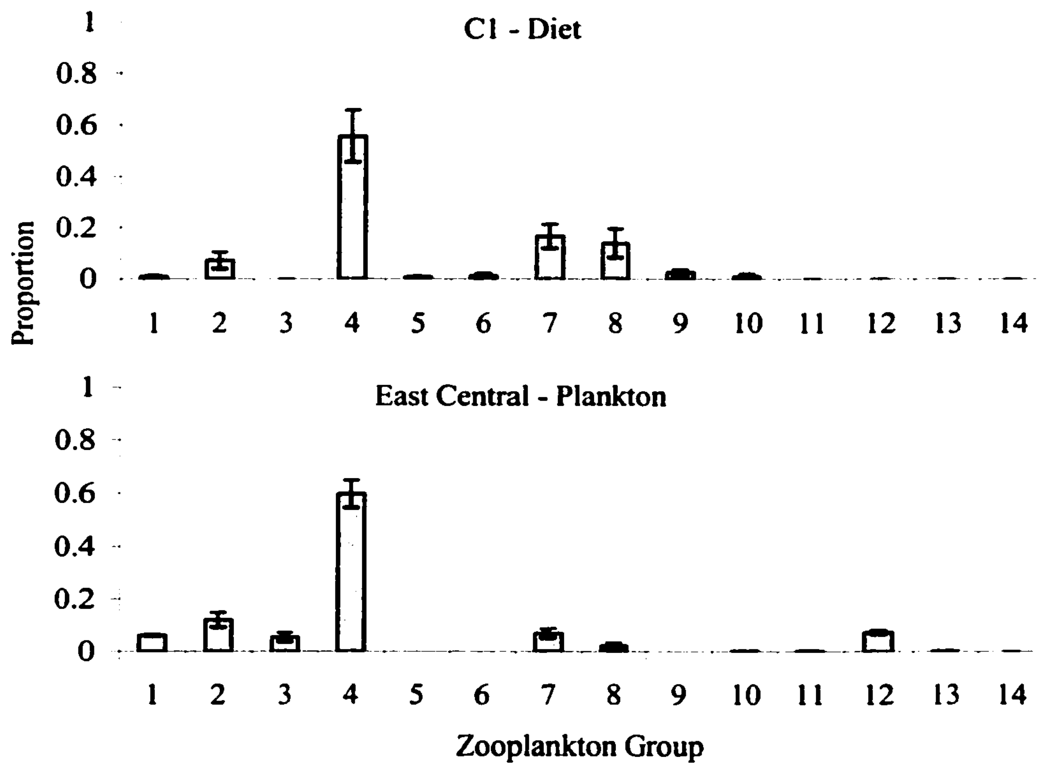

Figure 2.14. Proportions of zooplankton numbers in juvenile pink salmon diets at C1 (top panel) and in the environment as sampled with BONGO nets (bottom panel) in East Central PWS . Zooplankton groups are arranged in approximate order of increasing size on the x-axis. Standard error bars are shown. Zooplankton data provided by Purcell (personal communication). Zooplankton groups: 1. other, 2. Bivalves, 3. Eggs, 4. Small calanoid copepods, 5. Gastropods, 6. Crab zoeae, 7. Cladocerans, 8. Barnacle nauplii, 9. Barnacle cyprids, 10. Amphipods, 11. Large calanoid copepods, 12. Larvaceans, 13. Chaetognaths, 14. Euphausiids.

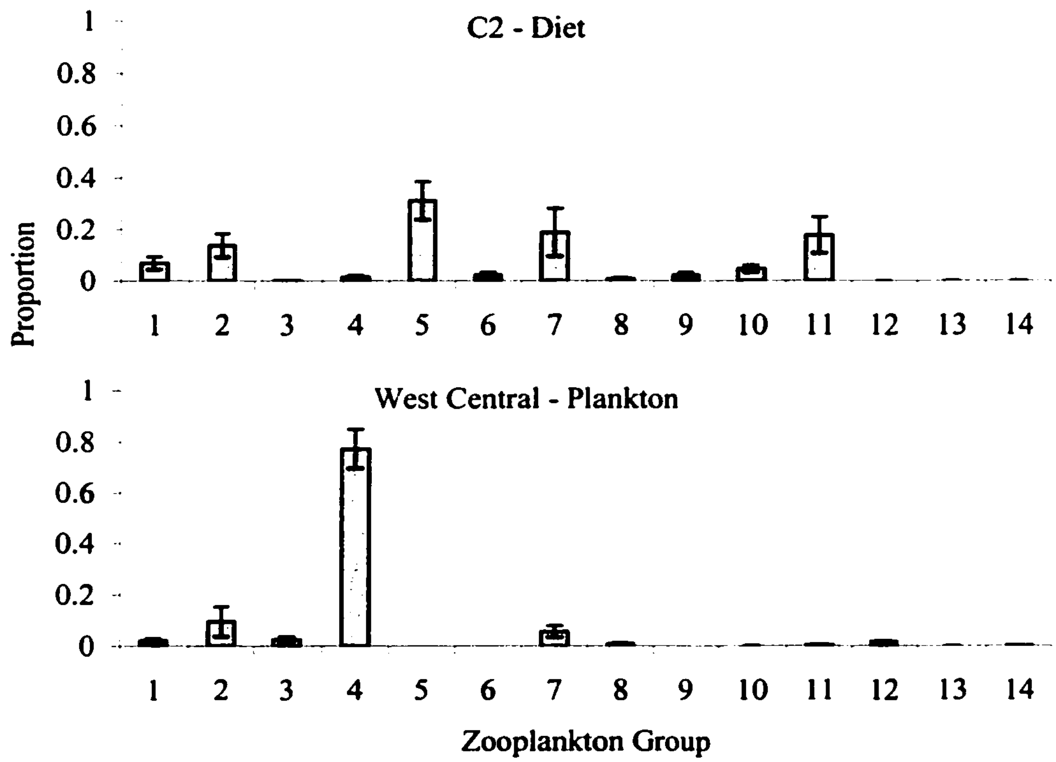

Figure 2.15. Proportions of zooplankton numbers in juvenile pink salmon diets at C2 (top panel) and in the environment as sampled with BONGO nets (bottom panel) in West Central PWS. Zooplankton groups are arranged in approximate order of increasing size on the x-axis. Standard error bars are shown. Zooplankton data provided by Purcell (personal communication). Zooplankton groups: 1. other, 2. Bivalves, 3. Eggs, 4. Small calanoid copepods, 5. Gastropods, 6. Crab zoeae, 7. Cladocerans, 8. Barnacle nauplii, 9. Barnacle cyprids, 10. Amphipods, 11. Large calanoid copepods, 12. Larvaceans, 13. Chaetognaths, 14. Euphausiids.

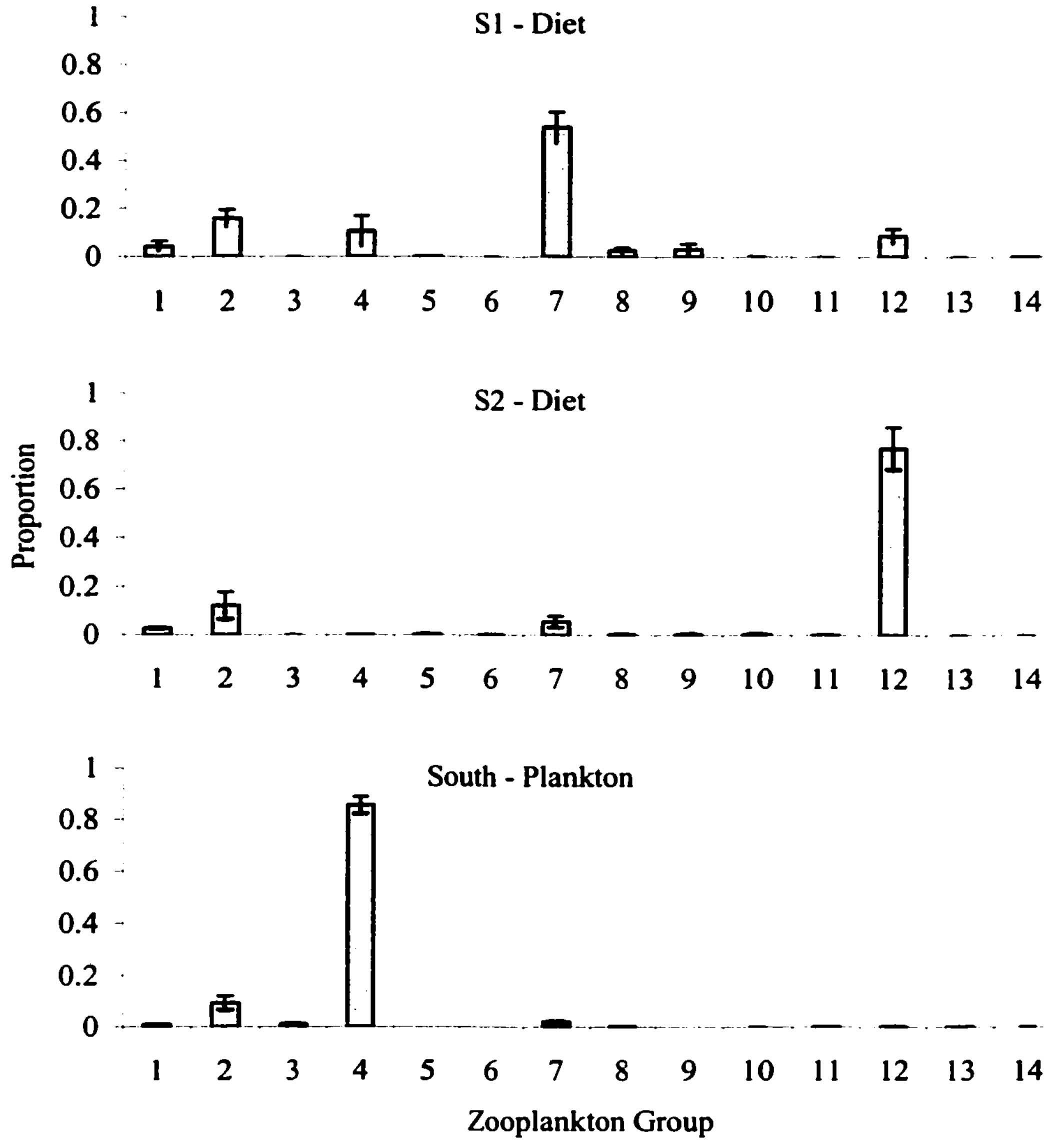

Figure 2.16. Proportions of zooplankton numbers in juvenile pink salmon diets at S1 (top panel) and S2 (middle panel) and in the environment as sampled with BONGO nets (bottom panel) in Southwest PWS. Zooplankton groups are arranged in approximate order of increasing size on the x-axis. Standard error bars are shown. Zooplankton data provided by Purcell (personal communication). Zooplankton groups: 1. other, 2. Bivalves, 3. Eggs, 4. Small calanoid copepods, 5. Gastropods, 6. Crab zoeae, 7. Cladocerans, 8. Barnacle nauplii, 9. Barnacle cyprids, 10. Amphipods, 11. Large calanoid copepods, 12. Larvaceans, 13. Chaetognaths, 14. Euphausiids.

Table 2.1. Dates and stations where samples were collected. The number of pink salmon examined for diet are shown.

	Area	Date	Station	Latitude (deg. min.)		Longitude (deg. min.)		# pink salmon examined for diet
GLOBEC	GOA	July 15	GAK 1i	59	46.24	149	23.32	6
		July 14	GAK 2	59	41.54	149	19.66	2
		July 7 and 14	GAK 2i	59	36.39	149	18.29	13
APEX	PWS	July 15	N1	60	38.89	146	27.69	10
		July 15	N2	60	39.54	146	36.03	13
		July 16	C1	60	37.92	147	15.57	10
		July 17	C2	60	38.85	147	37.87	10
		July 18	S1	60	13.61	148	10.57	10
		July 19	S2	60	12.06	148	4.75	10
OCC	GOA	August 3	CD1	58	50.14	152	20.36	8
		August 3	CD2	58	50.40	152	44.98	10
		August 1	CP1	59	26.46	148	26.34	10
		August 1	CP2	59	55.17	148	26.82	10
		August 2	GP	59	10.09	150	55.65	10
GLOBEC	GOA	October 4	GAK 1	59	50.05	149	29.18	5
		October 8	GAK 2	59	41.49	149	20.05	5
		October 8	GAK 4	59	24.51	149	3.34	8
		October 8	GAK 5	59	18.24	148	53.33	8
		October 6	GAK 6	59	6.48	148	45.96	9

Table 2.2. General taxonomic categories of pink salmon prey. Prey weights and sources used in the diet analysis are shown.

Prey Item	Wet weight (mg)	Source
Large calanoid copepod (>2.5 mm)	0.616	laboratory
Small calanoid copepods (<2.5 mm)	0.030	Coyle personal communication
Hyperiid amphipod	0.391	laboratory
Euphausiids (young)	58.322	laboratory
Insect	5.598	laboratory
Cladoceran	0.070	laboratory
Larvacean	1.487	Coyle personal communication
Gastropod	0.038	laboratory
Fish	10.748	laboratory
Crab megalops	7.378	laboratory
Crab zoeae	0.050	Cooney et al. 1981 (assume 80% water)
Barnacle nauplii	0.169	Coyle personal communication
Barnacle cyprid	0.219	Coyle personal communication
Bivalve	0.001	Coyle personal communication
Ostracod	1.428	Coyle personal communication
Pteropod (*Limacina* sp.)	0.343	laboratory
Pteropod (*Clio* sp.)	24.221	laboratory
Polychaete	22.000	Coyle personal communication
Polychaete larvae	0.038	laboratory
Invertebrate egg	0.010	Coyle personal communication
Unidentified crustacean	1.690	Coyle personal communication

Table 2.3. Locations, dates, and times of plankton samples collected in July, 1998. Station names do not match up to station names where fish samples were collected.

Area	Station	Day of July	Time	Latitude	Longitude	Bottom depth (m)	Gear depth (m)
Northeast	981N8	14	23:27	60 41.873	146 14.372	146	60
Northeast	981N7	15	0:35	60 40.722	146 17.962	132	60
Northeast	981N4	15	4:05	60 42.167	146 19.883	56	55
Northeast	981N5	15	22:42	60 43.976	146 19.777	25	22
Northeast	981N3	15	23:27	60 41.622	146 23.026	41	35
Northeast	981N6	16	0:10	60 39.117	146 22.336	118	60
Northeast	981N2	16	1:46	60 38.908	146 27.075	43	40
Northeast	981N1	16	3:18	60 39.639	146 35.287	37	30
East Central	981C8	16	22:52	60 37.829	147 17.273	105	60
East Central	981C7	17	0:11	60 39.773	147 14.837	140	60
East Central	981C6	17	1:23	60 41.161	147 14.620	161	60
East Central	981C5	17	2:39	60 43.29	147 15.446	170	60
West Central	981C1	17	22:55	60 43.92	147 33.803	592	60
West Central	981C2	18	0:13	60 40.816	147 33.253	>275	60
West Central	981C3	18	1:25	60 38.787	147 36.651	560	60
West Central	981C4	18	2:35	60 36.791	147 36.734	585	60
Southwest	981S2	18	22:34	60 16.808	148 11.346	151	60
Southwest	981S1	18	23:25	60 18.934	148 10.219	181	60
Southwest	981S3	19	0:35	60 17.184	148 7.824	94	60
Southwest	981S4	19	1:52	60 13.362	148 9.920	108	60
Southwest	981S6	19	22:35	60 11.759	148 5.482	238	60
Southwest	981S5	19	23:45	60 15.604	148 3.635	485	60
Southwest	981S7	20	0:50	60 14.925	147 58.993	640	60
Southwest	981S8	20	2:19	60 9.296	147 59.507	256	60

Table 2.4. Zooplankton samples were sorted to these major groupings. The stomach contents of juvenile pink salmon sampled in PWS were also sorted to include these zooplankton groups.

1 Small copepod(<2.5 mm)
2 Large copepod(>2.5 mm)
3 Cladocera
4 Veliger
5 Larvacean
6 Ostracod
7 Gymnosomate pteropod
8 Amphipod
9 Decapod
10 Chaetognath
11 Barnacle nauplii
12 Copepod nauplii
13 Euphausiacea
14 Echinodermata larva
15 Polychaete larva
16 Hemichordata larva
17 Eggs
18 Jellyfish

APPENDIX

Table A-2.1. Average proportions of prey numbers in pink salmon diets. Samples were collected in July, 1998 in the GOA. Standard errors and sample sizes are shown.

Average Number Proportion	GAK1i	GAK2	GAK2i
Barnacle nauplii	0.0000	0.0000	0.0000
Bivalves	0.0583	0.0073	0.0448
Cladocerans	0.0097	0.1305	0.3418
Crab Megalops	0.0000	0.0000	0.0000
Euphausiids	0.0044	0.5162	0.0077
Fish	0.0000	0.0000	0.0000
Gastropods	0.0293	0.0775	0.2782
Hyperiid amphipods	0.0000	0.0000	0.0025
Large copepod	0.3886	0.0601	0.0985
Larvaceans	0.4309	0.1370	0.0568
Small copepod	0.0144	0.0062	0.0329
Limacina sp.	0.0000	0.0000	0.0000
Clio sp.	0.0000	0.0000	0.0000
Other	0.0643	0.0651	0.1368

Standard Error	GAK1i	GAK2	GAK2i
Barnacle nauplii	0.0000	0.0000	0.0000
Bivalves	0.0583	0.0025	0.0216
Cladocerans	0.0038	0.1305	0.1041
Crab Megalops	0.0000	0.0000	0.0000
Euphausiids	0.0044	0.0306	0.0067
Fish	0.0000	0.0000	0.0000
Gastropods	0.0261	0.0727	0.0950
Hyperiid amphipods	0.0000	0.0000	0.0013
Large copepod	0.1241	0.0601	0.0591
Larvaceans	0.1698	0.1370	0.0468
Small copepod	0.0082	0.0062	0.0150
Limacina sp.	0.0000	0.0000	0.0000
Clio sp.	0.0000	0.0000	0.0000
Other	0.0516	0.0454	0.0609

Sample Size	GAK1i	GAK2	GAK2i
	6	2	13

Table A-2.2. Average proportions of prey biomass in pink salmon diets. Samples were collected in July, 1998 in the GOA. Standard errors and sample sizes are shown.

Average Biomass Proportions	GAK1i	GAK2	GAK2i
Barnacle nauplii	0.0000	0.0000	0.0000
Bivalves	0.0004	0.0000	0.0008
Cladocerans	0.0007	0.0003	0.2581
Crab Megalops	0.0000	0.0000	0.0000
Euphausiids	0.1153	0.9912	0.1330
Fish	0.0000	0.0000	0.0000
Gastropods	0.0016	0.0001	0.0850
Hyperiid amphipods	0.0000	0.0000	0.0095
Large copepod	0.2791	0.0004	0.1117
Larvaceans	0.4807	0.0071	0.1480
Small copepod	0.0210	0.0001	0.0719
Limacina sp.	0.0000	0.0000	0.0000
Clio sp.	0.0000	0.0000	0.0000
Other	0.1012	0.0009	0.1820

Standard Error	GAK1i	GAK2	GAK2i
Barnacle nauplii	0.0000	0.0000	0.0000
Bivalves	0.0004	0.0000	0.0005
Cladocerans	0.0004	0.0003	0.1005
Crab Megalops	0.0000	0.0000	0.0000
Euphausiids	0.1153	0.0069	0.0866
Fish	0.0000	0.0000	0.0000
Gastropods	0.0015	0.0001	0.0398
Hyperiid amphipods	0.0000	0.0000	0.0059
Large copepod	0.1247	0.0004	0.0627
Larvaceans	0.1671	0.0071	0.0765
Small copepod	0.0160	0.0001	0.0340
Limacina sp.	0.0000	0.0000	0.0000
Clio sp.	0.0000	0.0000	0.0000
Other	0.0644	0.0000	0.0932

Sample Size	GAK1i	GAK2	GAK2i
	6	2	13

Table A-2.3. Average proportions of prey numbers in pink salmon diets. Samples were collected in July, 1998 in PWS. Standard errors and sample sizes are shown.

Average Number Proportion	N1	N2	C1	C2	S1	S2
Barnacle nauplii	0.0150	0.0100	0.1401	0.0066	0.0262	0.0041
Bivalves	0.1134	0.0274	0.0720	0.1382	0.1591	0.1208
Cladocerans	0.8521	0.1015	0.1675	0.1887	0.5400	0.0572
Crab Megalops	0.0000	0.0000	0.0000	0.0000	0.0000	0.0015
Euphausiids	0.0000	0.0002	0.0000	0.0000	0.0015	0.0003
Fish	0.0000	0.0006	0.0000	0.0047	0.0000	0.0000
Gastropods	0.0017	0.0001	0.0070	0.3103	0.0017	0.0039
Hyperiid amphipods	0.0003	0.0002	0.0095	0.0473	0.0010	0.0040
Large copepod	0.0000	0.8107	0.0000	0.1765	0.0000	0.0028
Larvaceans	0.0000	0.0000	0.0000	0.0000	0.0872	0.7698
Small copepod	0.0119	0.0313	0.5566	0.0154	0.1071	0.0014
Limacina sp.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Clio sp.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Other	0.0056	0.0179	0.0472	0.1124	0.0763	0.0342

Standard Error	N1	N2	C1	C2	S1	S2
Barnacle nauplii	0.0055	0.0051	0.0569	0.0040	0.0109	0.0029
Bivalves	0.0596	0.0145	0.0325	0.0451	0.0350	0.0551
Cladocerans	0.0576	0.0415	0.0469	0.0920	0.0645	0.0221
Crab Megalops	0.0000	0.0000	0.0000	0.0000	0.0000	0.0010
Euphausiids	0.0000	0.0002	0.0000	0.0000	0.0015	0.0003
Fish	0.0000	0.0003	0.0000	0.0039	0.0000	0.0000
Gastropods	0.0013	0.0001	0.0034	0.0738	0.0009	0.0026
Hyperiid amphipods	0.0003	0.0002	0.0095	0.0130	0.0007	0.0037
Large copepod	0.0000	0.0516	0.0000	0.0700	0.0000	0.0012
Larvaceans	0.0000	0.0000	0.0000	0.0000	0.0291	0.0878
Small copepod	0.0049	0.0125	0.1003	0.0060	0.0632	0.0008
Limacina sp.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Clio sp.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Other	0.0018	0.0050	0.0157	0.0277	0.0308	0.0072

Sample Size	N1	N2	C1	C2	S1	S2
	10	13	10	10	10	10

Table A-2.4. Average proportions of prey biomass in pink salmon diets. Samples were collected in July, 1998 in PWS. Standard errors and sample sizes are shown.

Average Biomass Proportion	N1	N2	C1	C2	S1	S2
Barnacle nauplii	0.0363	0.0040	0.2659	0.0074	0.0199	0.0028
Bivalves	0.0035	0.0001	0.0017	0.0017	0.0015	0.0004
Cladocerans	0.9229	0.0169	0.1390	0.1542	0.2144	0.0075
Crab Megalops	0.0000	0.0000	0.0000	0.0000	0.0000	0.0351
Euphausiids	0.0000	0.0000	0.0000	0.0000	0.0894	0.0119
Fish	0.0000	0.0044	0.0000	0.0638	0.0000	0.0000
Gastropods	0.0011	0.0000	0.0072	0.0599	0.0003	0.0006
Hyperiid amphipods	0.0019	0.0001	0.0539	0.0855	0.0005	0.0079
Large copepod	0.0000	0.9415	0.0000	0.4139	0.0000	0.0028
Larvaceans	0.0000	0.0000	0.0000	0.0000	0.3340	0.8757
Small copepod	0.0051	0.0018	0.4066	0.0028	0.0207	0.0000
Limacina sp.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Clio sp.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Other	0.0292	0.0312	0.1258	0.2108	0.3193	0.0553

Standard Error	N1	N2	C1	C2	S1	S2
Barnacle nauplii	0.0128	0.0022	0.0878	0.0042	0.0136	0.0026
Bivalves	0.0024	0.0000	0.0008	0.0007	0.0007	0.0004
Cladocerans	0.0235	0.0076	0.0592	0.0877	0.0847	0.0056
Crab Megalops	0.0000	0.0000	0.0000	0.0000	0.0000	0.0314
Euphausiids	0.0000	0.0000	0.0000	0.0000	0.0894	0.0119
Fish	0.0000	0.0026	0.0000	0.0491	0.0000	0.0000
Gastropods	0.0008	0.0000	0.0039	0.0131	0.0002	0.0005
Hyperiid amphipods	0.0019	0.0001	0.0539	0.0248	0.0004	0.0078
Large copepod	0.0000	0.0187	0.0000	0.1117	0.0000	0.0017
Larvaceans	0.0000	0.0000	0.0000	0.0000	0.0823	0.0865
Small copepod	0.0021	0.0007	0.1078	0.0011	0.0168	0.0000
Limacina sp.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Clio sp.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Other	0.0121	0.0176	0.0394	0.0756	0.0965	0.0376

Sample Size	N1	N2	C1	C2	S1	S2
	10	13	10	10	10	10

Table A-2.5. Average proportions of prey numbers in pink salmon diets. Samples were collected in August, 1998 in the GOA. Standard errors and sample sizes are shown.

Average Number Proportion	CP1	CP2	CD1	CD2	GP
Barnacle nauplii	0.0000	0.0000	0.0000	0.0000	0.0020
Bivalves	0.0000	0.0000	0.0000	0.0000	0.0000
Cladocerans	0.0000	0.0017	0.0000	0.0000	0.0000
Crab Megalops	0.0000	0.0000	0.0000	0.0099	0.0000
Euphausiids	0.0397	0.0010	0.0031	0.0474	0.0000
Fish	0.0000	0.0020	0.0063	0.0000	0.0000
Gastropods	0.0000	0.0000	0.1621	0.0505	0.5988
Hyperiid amphipods	0.0270	0.0079	0.2805	0.4948	0.0111
Large copepod	0.1459	0.0074	0.0701	0.0284	0.1586
Larvaceans	0.0000	0.4842	0.0697	0.2016	0.2249
Small copepod	0.0147	0.0017	0.0040	0.0017	0.0000
Limacina sp.	0.3773	0.4725	0.0000	0.0000	0.0000
Clio sp.	0.0000	0.0000	0.0000	0.0000	0.0000
Other	0.3954	0.0215	0.4042	0.1658	0.0046

Standard Error	CP1	CP2	CD1	CD2	GP
Barnacle nauplii	0.0000	0.0000	0.0000	0.0000	0.0020
Bivalves	0.0000	0.0000	0.0000	0.0000	0.0000
Cladocerans	0.0000	0.0012	0.0000	0.0000	0.0000
Crab Megalops	0.0000	0.0000	0.0000	0.0055	0.0000
Euphausiids	0.0295	0.0010	0.0031	0.0312	0.0000
Fish	0.0000	0.0020	0.0063	0.0000	0.0000
Gastropods	0.0000	0.0000	0.0763	0.0279	0.1008
Hyperiid amphipods	0.0109	0.0070	0.1358	0.1136	0.0040
Large copepod	0.0868	0.0048	0.0594	0.0107	0.0557
Larvaceans	0.0000	0.1602	0.0537	0.1325	0.1107
Small copepod	0.0127	0.0014	0.0040	0.0015	0.0000
Limacina sp.	0.1113	0.1582	0.0000	0.0000	0.0000
Clio sp.	0.0000	0.0000	0.0000	0.0000	0.0000
Other	0.1214	0.0102	0.1057	0.0608	0.0024

Sample Size	CP1	CP2	CD1	CD2	GP
	10	10	8	10	10

Table A-2.6. Average proportions of prey biomass in pink salmon diets. Samples were collected in August, 1998 in the GOA. Standard errors and sample sizes are shown.

Average Biomass Proportion	CP1	CP2	CD1	CD2	GP
Barnacle nauplii	0.0000	0.0000	0.0000	0.0000	0.0003
Bivalves	0.0000	0.0000	0.0000	0.0000	0.0000
Cladocerans	0.0000	0.0001	0.0000	0.0000	0.0000
Crab Megalops	0.0000	0.0000	0.0000	0.0543	0.0000
Euphausiids	0.1695	0.0255	0.0518	0.0581	0.0000
Fish	0.0000	0.0198	0.0403	0.0000	0.0000
Gastropods	0.0000	0.0000	0.0060	0.0013	0.1462
Hyperiid amphipods	0.0409	0.0034	0.1170	0.2142	0.0256
Large copepod	0.1461	0.0069	0.0581	0.0155	0.4136
Larvaceans	0.0000	0.5054	0.0825	0.2029	0.3524
Small copepod	0.0003	0.0001	0.0001	0.0000	0.0000
Limacina sp.	0.2320	0.4307	0.0000	0.0000	0.0000
Clio sp.	0.0000	0.0000	0.0000	0.0000	0.0000
Other	0.4112	0.0079	0.6441	0.4536	0.0619

Standard Error	CP1	CP2	CD1	CD2	GP
Barnacle nauplii	0.0000	0.0000	0.0000	0.0000	0.0003
Bivalves	0.0000	0.0000	0.0000	0.0000	0.0000
Cladocerans	0.0000	0.0001	0.0000	0.0000	0.0000
Crab Megalops	0.0000	0.0000	0.0000	0.0240	0.0000
Euphausiids	0.1139	0.0255	0.0518	0.0503	0.0000
Fish	0.0000	0.0198	0.0403	0.0000	0.0000
Gastropods	0.0000	0.0000	0.0028	0.0005	0.0484
Hyperiid amphipods	0.0302	0.0025	0.0745	0.0612	0.0139
Large copepod	0.0968	0.0042	0.0473	0.0055	0.1331
Larvaceans	0.0000	0.1631	0.0590	0.1326	0.1458
Small copepod	0.0003	0.0000	0.0001	0.0000	0.0000
Limacina sp.	0.0972	0.1499	0.0000	0.0000	0.0000
Clio sp.	0.0000	0.0000	0.0000	0.0000	0.0000
Other	0.1500	0.0061	0.1297	0.1028	0.0407

Sample Size	CP1	CP2	CD1	CD2	GP
	10	10	8	10	10

Table A-2.7. Average proportions of prey numbers in pink salmon diets. Samples were collected in October, 1998 in the GOA. Standard errors and sample sizes are shown.

Average Number Proportion	GAK1	GAK2	GAK4	GAK5	GAK6
Barnacle nauplii	0.0000	0.0000	0.0000	0.0000	0.0000
Bivalves	0.0000	0.0000	0.0000	0.0000	0.0000
Cladocerans	0.0000	0.0000	0.0000	0.0000	0.0000
Crab Megalops	0.2407	0.0000	0.0222	0.0000	0.0166
Euphausiids	0.0724	0.0039	0.0605	0.0128	0.0000
Fish	0.0000	0.0000	0.0042	0.0000	0.1079
Gastropods	0.0027	0.0000	0.0014	0.0000	0.0000
Hyperiid amphipods	0.4532	0.6243	0.1307	0.2150	0.0794
Large copepod	0.0792	0.0545	0.2990	0.1308	0.1372
Larvaceans	0.0000	0.0000	0.0000	0.0000	0.0000
Small copepod	0.0133	0.0123	0.0234	0.0717	0.0476
Limacina sp.	0.0000	0.0078	0.0050	0.0000	0.0000
Clio sp.	0.0000	0.2616	0.4298	0.2921	0.1164
Other	0.1384	0.0355	0.0237	0.2777	0.4949

Standard Error	GAK1	GAK2	GAK4	GAK5	GAK6
Barnacle nauplii	0.0000	0.0000	0.0000	0.0000	0.0000
Bivalves	0.0000	0.0000	0.0000	0.0000	0.0000
Cladocerans	0.0000	0.0000	0.0000	0.0000	0.0000
Crab Megalops	0.1128	0.0000	0.0144	0.0000	0.0158
Euphausiids	0.0702	0.0039	0.0252	0.0111	0.0000
Fish	0.0000	0.0000	0.0035	0.0000	0.0765
Gastropods	0.0027	0.0000	0.0014	0.0000	0.0000
Hyperiid amphipods	0.1636	0.1138	0.0696	0.1101	0.0538
Large copepod	0.0579	0.0335	0.1426	0.1003	0.1063
Larvaceans	0.0000	0.0000	0.0000	0.0000	0.0000
Small copepod	0.0133	0.0083	0.0091	0.0318	0.0337
Limacina sp.	0.0000	0.0078	0.0027	0.0000	0.0000
Clio sp.	0.0000	0.1191	0.1276	0.1675	0.0683
Other	0.0695	0.0165	0.0072	0.1168	0.1421

Sample Size	GAK1	GAK2	GAK4	GAK5	GAK6
	5	5	8	8	9

Table A-2.8. Average proportions of prey biomass in pink salmon diets. Samples were collected in October, 1998 in the GOA. Standard errors and sample sizes are shown.

Average Biomass Proportion	GAK1	GAK2	GAK4	GAK5	GAK6
Barnacle nauplii	0.0000	0.0000	0.0000	0.0000	0.0000
Bivalves	0.0000	0.0000	0.0000	0.0000	0.0000
Cladocerans	0.0000	0.0000	0.0000	0.0000	0.0000
Crab Megalops	0.4290	0.0000	0.0131	0.0000	0.0055
Euphausiids	0.1730	0.0163	0.2066	0.0960	0.0000
Fish	0.0000	0.0000	0.0088	0.0000	0.2419
Gastropods	0.0004	0.0000	0.0007	0.0000	0.0000
Hyperiid amphipods	0.2980	0.4173	0.0435	0.0460	0.0076
Large copepod	0.0306	0.0327	0.1495	0.0225	0.0147
Larvaceans	0.0000	0.0000	0.0000	0.0000	0.0000
Small copepod	0.0001	0.0002	0.0006	0.0004	0.0002
Limacina sp.	0.0000	0.0004	0.0003	0.0111	0.0000
Clio sp.	0.0000	0.5229	0.5600	0.1267	0.2760
Other	0.0688	0.0103	0.0169	0.6973	0.4541

Standard Error	GAK1	GAK2	GAK4	GAK5	GAK6
Barnacle nauplii	0.0000	0.0000	0.0000	0.0000	0.0000
Bivalves	0.0000	0.0000	0.0000	0.0000	0.0000
Cladocerans	0.0000	0.0000	0.0000	0.0000	0.0000
Crab Megalops	0.1825	0.0000	0.0089	0.0000	0.0047
Euphausiids	0.1319	0.0163	0.0666	0.0765	0.0000
Fish	0.0000	0.0000	0.0083	0.0000	0.1383
Gastropods	0.0004	0.0000	0.0007	0.0000	0.0000
Hyperiid amphipods	0.1665	0.2026	0.0161	0.0261	0.0052
Large copepod	0.0194	0.0206	0.0942	0.0181	0.0104
Larvaceans	0.0000	0.0000	0.0000	0.0000	0.0000
Small copepod	0.0001	0.0002	0.0004	0.0002	0.0002
Limacina sp.	0.0000	0.0004	0.0002	0.0119	0.0000
Clio sp.	0.0000	0.2136	0.1158	0.0919	0.1418
Other	0.0382	0.0072	0.0074	0.1634	0.1528

Sample Size	GAK1	GAK2	GAK4	GAK5	GAK6
	5	5	8	8	9

Table A-2.9. Average density of zooplankton in BONGO samples. Samples were collected in July, 1998 in PWS. Standard errors and samples sizes are shown. Data was provided by Purcell (personal communication).

Average Number/m^2	N	EC	WC	S
Small copepod (<2.5 mm)	36,592.4	35,286.6	118,216.6	177,834.4
Large copepod (>2.5 mm)	31.8	127.4	636.9	382.2
Cladocera	12,579.6	4,522.3	7,133.8	3,949.0
Veliger	14,172.0	7,707.0	10,700.6	18,535.0
Larvacean	4,331.2	4,394.9	2,547.8	636.9
Ostracod	222.9	0	509.6	636.9
Gymnosomate pteropod	0	0	254.8	0
Amphipod	0	63.7	127.4	0
Decapod	509.6	509.6	0	254.8
Chaetognath	95.5	63.7	0	191.1
Barnacle nauplii	2,675.2	1,401.3	1,146.5	828.0
Copepod nauplii	1,433.1	1,273.9	1,019.1	636.9
Euphausiacea	31.8	0	254.8	127.4
Echinodermata larva	828.0	1,719.7	764.3	191.1
Polychaete larva	286.6	254.8	127.4	127.4
Hemichordata larva	63.7	0	0	0
Eggs	191.1	3,694.3	3,949.0	2,547.8
Jellyfish	1,082.8	10.2	40.8	20.4
Total	75,127.4	61,029.3	147,429.3	206,899.4

Standard Error	N	EC	WC	S
Small copepod (<2.5 mm)	6,642.9	3,081.1	23,383.1	30,228.3
Large copepod (>2.5 mm)	31.8	127.4	320.6	159.7
Cladocera	3,625.8	1,472.3	1,801.5	942.3
Veliger	2,945.7	2,335.9	4,807.1	5,748.0
Larvacean	2,195.4	745.5	657.8	250.2
Ostracod	131.3	0	360.3	209.9
Gymnosomate pteropod	0	0	147.1	0
Amphipod	0	63.7	127.4	0
Decapod	127.4	208.0	0	96.3
Chaetognath	67.0	63.7	0	93.2
Barnacle nauplii	425.2	788.7	482.3	234.6
Copepod nauplii	605.1	441.3	294.2	357.1
Euphausiacea	31.8	0	147.1	83.4
Echinodermata larva	616.1	191.1	328.9	134.0
Polychaete larva	131.3	147.1	127.4	127.4
Hemichordata larva	63.7	0	0	0
Eggs	79.8	1,561.9	2,084.1	1,000.7
Jellyfish	336.2	10.2	40.8	20.4

Sample Size	N	EC	WC	S
	8	4	4	8

Table A-2.10. Proportions of zooplankton numbers sampled with BONGO nets. Data was provided by Purcell (personal communication).

	N	EC	WC	S
Small copepod (<2.5 mm)	0.487	0.578	0.802	0.860
Large copepod (>2.5 mm)	0.000	0.002	0.004	0.002
Cladocera	0.167	0.074	0.048	0.019
Veliger	0.189	0.126	0.073	0.090
Larvacean	0.058	0.072	0.017	0.003
Ostracod	0.003	0.000	0.003	0.003
Gymnosomate pteropod	0.000	0.000	0.002	0.000
Amphipod	0.000	0.001	0.001	0.000
Decapod	0.007	0.008	0.000	0.001
Chaetognath	0.001	0.001	0.000	0.001
Barnacle nauplii	0.036	0.023	0.008	0.004
Copepod nauplii	0.019	0.021	0.007	0.003
Euphausiacea	0.000	0.000	0.002	0.001
Echinodermata larva	0.011	0.028	0.005	0.001
Polychaete larva	0.004	0.004	0.001	0.001
Hemichordata larva	0.001	0.000	0.000	0.000
Eggs	0.003	0.061	0.027	0.012
Jellyfish	0.014	0.000	0.000	0.000

Table A-2.11. Proportions of prey numbers in all fish examined at station N1 in PWS. Average values and standard errors are shown for each prey group.

N1	Fish Number											
	1	2	3	4	5	6	7	8	9	10	Average	se
Large copepod (>2.5 mm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Small copepod (<2.5 mm)	0.046	0.004	0.026	0.000	0.000	0.024	0.010	0.000	0.001	0.006	0.012	0.005
Euphausiids	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Amphipods	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000
Malacostracan eye	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Invertebrate egg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chaetognath	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Unidentified crustacean	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Crab megalops	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Crab zoea	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000
Shrimp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pteropods (*Clio* sp)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pteropods (*Limacina* sp)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Larval fish	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cladocerans	0.947	0.752	0.953	0.726	0.400	0.920	0.973	0.918	0.964	0.969	0.852	0.058
Gastropod	0.000	0.003	0.000	0.013	0.000	0.000	0.000	0.001	0.000	0.000	0.002	0.001
Bivalves	0.003	0.171	0.006	0.234	0.600	0.024	0.004	0.055	0.020	0.016	0.113	0.060
Ostracod	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Larvaceans	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Barnacle cyprids	0.001	0.007	0.003	0.017	0.000	0.011	0.002	0.007	0.002	0.002	0.005	0.002
Barnacle exuvia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Barnacle nauplii	0.003	0.062	0.013	0.009	0.000	0.019	0.011	0.015	0.011	0.007	0.015	0.005
Insect	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Polychaete	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Polychaete larvae	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A-2.12. Proportions of prey numbers in all fish examined at station N2 in PWS. Average values and standard errors are shown for each prey group.

N2	Fish Number													
	1	2	3	4	5	6	7	8	9	10	11	12	Average	se
Large copepod (>2.5 mm)	0.419	0.975	0.905	0.986	0.979	0.721	0.779	0.942	0.958	0.607	0.550	0.909	0.811	0.046
Small copepod (<2.5 mm)	0.079	0.000	0.000	0.000	0.000	0.000	0.155	0.019	0.025	0.036	0.000	0.061	0.031	0.014
Euphausiids	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Amphipods	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Malacostracan eye	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Invertebrate egg	0.000	0.000	0.000	0.000	0.000	0.000	0.058	0.008	0.000	0.000	0.000	0.000	0.005	0.005
Chaetognath	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Unidentified crustacean	0.013	0.000	0.000	0.003	0.007	0.000	0.003	0.004	0.000	0.000	0.000	0.020	0.004	0.002
Crab megalops	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Crab zoea	0.000	0.000	0.004	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Shrimp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.001	0.001
Pteropods (*Clio* sp)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pteropods (*Limacina* sp)	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.001	0.001
Larval fish	0.003	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000
Cladocerans	0.465	0.021	0.027	0.005	0.000	0.202	0.000	0.016	0.017	0.121	0.344	0.000	0.102	0.034
Gastropod	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bivalves	0.017	0.002	0.004	0.000	0.014	0.061	0.003	0.004	0.000	0.190	0.033	0.000	0.027	0.017
Ostracod	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000
Larvaceans	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Barnacle cyprids	0.000	0.000	0.015	0.000	0.000	0.013	0.000	0.000	0.000	0.008	0.011	0.000	0.004	0.002
Barnacle exuvia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Barnacle nauplii	0.003	0.001	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.032	0.061	0.000	0.010	0.006
Insect	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Polychaete	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
Polychaete larvae	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001

Table A-2.13. Proportions of prey numbers in all fish examined at station C1 in PWS. Average values and standard errors are shown for each prey group.

C1	Fish Number											
	1	2	3	4	5	6	7	8	9	10	Average	se
Large copepod (>2.5 mm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Small copepod (<2.5 mm)	0.619	0.000	0.672	0.474	0.436	0.843	0.402	0.200	0.959	0.960	0.557	0.100
Euphausiids	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Amphipods	0.095	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.010
Malacostracan eye	0.048	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.005	0.005
Invertebrate egg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chaetognath	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Unidentified crustacean	0.000	0.012	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002
Crab megalops	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Crab zoea	0.095	0.000	0.000	0.006	0.000	0.000	0.017	0.000	0.000	0.000	0.012	0.009
Shrimp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pteropods (*Clio* sp)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pteropods (*Limacina* sp)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Larval fish	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cladocerans	0.095	0.329	0.098	0.128	0.502	0.120	0.144	0.217	0.025	0.016	0.167	0.047
Gastropod	0.000	0.005	0.034	0.000	0.002	0.012	0.009	0.000	0.000	0.008	0.007	0.003
Bivalves	0.000	0.227	0.161	0.006	0.019	0.024	0.262	0.013	0.000	0.008	0.072	0.033
Ostracod	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Larvaceans	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Barnacle cyprids	0.000	0.088	0.011	0.026	0.004	0.000	0.044	0.068	0.016	0.000	0.026	0.010
Barnacle exuvia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Barnacle nauplii	0.048	0.339	0.023	0.346	0.035	0.000	0.118	0.485	0.000	0.008	0.140	0.057
Insect	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Polychaete	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Polychaete larvae	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.017	0.000	0.000	0.002	0.002

Table A-2.14. Proportions of prey numbers in all fish examined at station C2 in PWS. Average values and standard errors are shown for each prey group.

C2	Fish Number											
	1	2	3	4	5	6	7	8	9	10	Average	se
Large copepod (>2.5 mm)	0.274	0.016	0.137	0.000	0.101	0.045	0.098	0.000	0.685	0.410	0.176	0.070
Small copepod (<2.5 mm)	0.041	0.007	0.020	0.004	0.000	0.006	0.000	0.054	0.000	0.022	0.015	0.006
Euphausiids	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Amphipods	0.014	0.004	0.117	0.001	0.084	0.000	0.061	0.081	0.047	0.065	0.047	0.013
Malacostracan eye	0.000	0.000	0.000	0.000	0.185	0.000	0.049	0.054	0.040	0.050	0.038	0.018
Invertebrate egg	0.000	0.000	0.000	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.002	0.002
Chaetognath	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Unidentified crustacean	0.000	0.000	0.000	0.000	0.017	0.003	0.024	0.054	0.000	0.000	0.010	0.006
Crab megalops	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Crab zoea	0.055	0.002	0.000	0.000	0.000	0.000	0.073	0.027	0.067	0.007	0.023	0.010
Shrimp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pteropods (*Clio* sp)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pteropods (*Limacina* sp)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Larval fish	0.000	0.000	0.039	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.005	0.004
Cladocerans	0.000	0.525	0.000	0.759	0.025	0.511	0.012	0.054	0.000	0.000	0.189	0.092
Gastropod	0.534	0.047	0.644	0.058	0.496	0.029	0.268	0.541	0.148	0.338	0.310	0.074
Bivalves	0.041	0.287	0.039	0.132	0.000	0.393	0.317	0.108	0.000	0.065	0.138	0.045
Ostracod	0.000	0.000	0.000	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.002	0.002
Larvaceans	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Barnacle cyprids	0.014	0.109	0.000	0.028	0.025	0.013	0.024	0.000	0.000	0.007	0.022	0.010
Barnacle exuvia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Barnacle nauplii	0.000	0.002	0.000	0.006	0.000	0.000	0.037	0.000	0.000	0.022	0.007	0.004
Insect	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Polychaete	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Polychaete larvae	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	0.027	0.000	0.005	0.011	0.025	0.000	0.037	0.027	0.013	0.014	0.016	0.004

Table A-2.15. Proportions of prey numbers in all fish examined at station S1 in PWS. Average values and standard errors are shown for each prey group.

S1	Fish Number											
	1	2	3	4	5	6	7	8	9	10	Average	se
Large copepod (>2.5 mm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Small copepod (<2.5 mm)	0.005	0.005	0.303	0.008	0.002	0.095	0.007	0.008	0.610	0.028	0.107	0.063
Euphausiids	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.001	0.001
Amphipods	0.003	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.001	0.001
Malacostracan eye	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.004	0.000	0.000	0.002	0.001
Invertebrate egg	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chaetognath	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Unidentified crustacean	0.000	0.005	0.000	0.000	0.000	0.004	0.000	0.000	0.002	0.000	0.001	0.001
Crab megalops	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Crab zoea	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Shrimp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pteropods (*Clio* sp)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pteropods (*Limacina* sp)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Larval fish	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cladocerans	0.524	0.607	0.205	0.443	0.525	0.674	0.869	0.694	0.238	0.621	0.540	0.064
Gastropod	0.000	0.000	0.000	0.008	0.004	0.000	0.000	0.000	0.005	0.000	0.002	0.001
Bivalves	0.158	0.218	0.041	0.098	0.380	0.170	0.022	0.283	0.085	0.137	0.159	0.035
Ostracod	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Larvaceans	0.284	0.018	0.205	0.071	0.060	0.046	0.022	0.002	0.034	0.130	0.087	0.029
Barnacle cyprids	0.005	0.042	0.016	0.212	0.015	0.004	0.022	0.004	0.003	0.000	0.032	0.020
Barnacle exuvia	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Barnacle nauplii	0.021	0.096	0.033	0.078	0.002	0.002	0.000	0.004	0.002	0.025	0.026	0.011
Insect	0.000	0.002	0.189	0.078	0.006	0.002	0.000	0.000	0.003	0.060	0.034	0.019
Polychaete	0.000	0.000	0.000	0.004	0.002	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Polychaete larvae	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.001	0.001
Other	0.000	0.002	0.008	0.000	0.004	0.002	0.022	0.002	0.013	0.000	0.005	0.002

Table A-2.16. Proportions of prey numbers in all fish examined at station S2 in PWS. Average values and standard errors are shown for each prey group.

S2	Fish Number											
	1	2	3	4	5	6	7	8	9	10	Average	se
Large copepod (>2.5 mm)	0.000	0.005	0.000	0.008	0.000	0.000	0.008	0.000	0.007	0.000	0.003	0.001
Small copepod (<2.5 mm)	0.007	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.001	0.001
Euphausiids	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000
Amphipods	0.000	0.037	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.004	0.004
Malacostracan eye	0.000	0.000	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002
Invertebrate egg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chaetognath	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Unidentified crustacean	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.011	0.007	0.000	0.002	0.001
Crab megalops	0.000	0.008	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.001	0.001
Crab zoea	0.000	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002
Shrimp	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pteropods (*Clio* sp)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pteropods (*Limacina* sp)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Larval fish	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cladocerans	0.028	0.203	0.046	0.168	0.053	0.025	0.005	0.015	0.003	0.026	0.057	0.022
Gastropod	0.007	0.026	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.004	0.003
Bivalves	0.194	0.589	0.097	0.056	0.094	0.050	0.022	0.008	0.000	0.097	0.121	0.055
Ostracod	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Larvaceans	0.734	0.013	0.827	0.722	0.828	0.899	0.939	0.943	0.937	0.856	0.770	0.088
Barnacle cyprids	0.000	0.032	0.004	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.004	0.003
Barnacle exuvia	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.020	0.000	0.002	0.002
Barnacle nauplii	0.000	0.029	0.004	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.004	0.003
Insect	0.003	0.000	0.000	0.003	0.000	0.000	0.000	0.008	0.003	0.000	0.002	0.001
Polychaete	0.000	0.003	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Polychaete larvae	0.028	0.029	0.016	0.025	0.016	0.017	0.011	0.015	0.010	0.015	0.018	0.002
Other	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.001	0.001

Chapter 3

Size and Condition of Wild and Hatchery Pink Salmon Juveniles in Prince William Sound, Alaska[3]

Abstract

Increased pink salmon hatchery releases and declining wild salmon runs in Prince William Sound (PWS) have raised concerns that hatchery pink salmon are having a negative impact on wild pink salmon. A unique opportunity existed to compare the energy content and length-weight relationships of wild and thermally marked hatchery juvenile pink salmon among different areas of PWS. Juvenile pink salmon were collected from six stations in three areas within Prince William Sound. There were significant differences in lengths of juvenile pink salmon among stations in PWS; however, there were no significant differences in length-weight relationships between the stations. Pink salmon in Whale Bay (71.5 mm, Southwest PWS) were the shortest fish sampled and those in Bainbridge Passage (92.4 mm, Southwest PWS) were the longest. The energy content of juvenile pink salmon did not differ significantly between wild and hatchery fish. Pink salmon (both hatchery and wild) sampled near Knowles Head (Northeast PWS) had significantly higher energy content than fish at all other stations. Pink salmon sampled east of Naked Island (East Central PWS) had the lowest energy

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content. Within the central area of PWS, Cannery Creek Hatchery pink salmon were significantly shorter than all other hatchery groups and the wild pink salmon. Solomon Gulch Hatchery pink salmon were the longest fish sampled in the central area of PWS. The energy content of pink salmon did not differ significantly among the hatchery groups and wild salmon. However, all hatchery pink salmon sampled west of Naked Island (West Central PWS) had significantly higher energy content than the hatchery pink salmon sampled east of Naked Island (East Central PWS). The consistencies in energy content among groups of fish from the same geographic area indicate processes occurring on local scales, such as the effects of stratification on secondary production or local depletion by planktivores, are important in determining the condition of juvenile pink salmon.

Introduction

Prince William Sound (PWS) is a large, complex, fjord-type estuary that supports large runs of hatchery and wild pink salmon (Niebauer et al. 1994). Salmon enhancement in PWS increased from the mid-1970's to 1989 (McNair 1997). Currently, PWS hatcheries release about 600 million pink fry annually. The increase in pink salmon hatchery releases has been correlated with a decline in wild salmon runs (Hilborn and Eggers 2000). Wild salmon returns in PWS peaked in 1983 and declined until 1995 (Cooney and Brodeur 1998). Despite increasing pink salmon returns, the body size of 45 of 47 North Pacific salmon stocks has been decreasing since the mid-1970's, and may be due to density-dependent factors, such as competition for food (Peterman 1987; Bigler et al. 1996). Intraspecific competition and, hence, food limitation may also occur as indicated by a negative correlation between the number of pink salmon smolts and their survival (Peterman 1978). Concern over declining wild stocks and returning salmon body size has led to the hypothesis that the carrying capacity of PWS, and possibly the GOA, for salmon has been reached (Beamish et al. 1997; Cooney and Brodeur 1998).

Studies have shown that pink salmon consume a relatively small proportion of the total available secondary production in PWS (Cooney 1993, Chapter 4). A critical assumption of these studies is that all zooplankton and fish are evenly distributed in their environment (Cooney 1993). Juvenile pink salmon occupy shallow bays in PWS for several weeks when they first enter salt water, creating the possibility for local prey depletion in areas where water column structure does not favor high primary and secondary production (Cooney et al. 1978). There is also the possibility that there is competition for zooplankton with planktivorous fishes that occupy the same habitat, such as herring, juvenile pollock, juvenile tomcod, sandlance, and capelin (Cooney et al. 1978; L. Haldorson, University of Alaska Fairbanks, personal communication). Local food depletion in areas of PWS would result in differences in fish growth and condition among areas. Fish that are in better condition and are larger would be expected to have a higher survival rate during the early marine stage, as the smaller, slower growing fish may experience higher predation mortality.

Juvenile pink salmon from the 1997 brood year were in better condition on the GOA shelf compared to those in PWS in July, suggesting that growth conditions were sub-optimal in PWS (Chapter 1). The purpose of this chapter is to investigate the condition of fish sampled in PWS. I examined the geographic variation in hatchery and wild juvenile pink salmon size and condition in PWS and relate it to zooplankton density and water column stability. I compared the length, weight, and energetic content of juvenile pink salmon (1) among different areas of PWS, (2) between hatchery and wild pink salmon in several areas of PWS, and (3) among hatchery release groups.

Methods and Material

Fish utilized in this analysis were the same as some of those described in Chapter 2. Salmon were sampled in Prince William Sound, Alaska, July 14-18, 1998 in three areas: northeast PWS in Port Gravina (N), central PWS around Naked Island (C), and southwest PWS in the vicinity of Whale Bay and Bainbridge Passage (S) (Figure 3.1).

Two stations from each area, where a large number of pink salmon were captured, were chosen for analyses: N1, N2, C1, C2, S1, and S2 (Figure 3.1 and Table 3.1).

Fish were collected with a blind purse seine (200 m long, 20 m deep, 25 mm stretched mesh) set at each station during daylight hours. Fish were frozen in seawater for laboratory analyses. In the laboratory, fish were thawed, blotted dry, measured, and weighed. Otoliths were removed and stored in 10% alcohol for later analysis. Otoliths were examined for thermal marks as described in Chapter 1. The stomach of each frozen fish was extracted and the contents removed. The stomach was rinsed, blotted dry, and returned to the body of the fish.

A sample of 25 fish from each station was dried. Each fish was blotted dry, then standard and fork lengths were measured to the nearest millimeter. The fish were then weighed to the nearest 0.001 gram. After otoliths and stomach contents were removed, the fish were weighed again and placed in a drying oven at 60° C until a stable weight was reached (approximately 48 hours depending on fish size). The fish were weighed when dried and then stored in a dessicator in a freezer. Dried fish were combusted in a Parr semi-microbomb calorimeter as described in Chapter 1.

Hatchery and Wild Salmon Comparisons

CCH pink salmon dominated the hatchery portion of the catches at all stations; therefore, comparisons were made between CCH and wild pink salmon (see results below). In each area the caloric content of 10 wild and 10 CCH pink salmon (about 5 wild and hatchery pink salmon from each of the two stations sampled) was determined.

A systematic random sample of the fish was analyzed. Lists of the fish from all stations were sorted into wild and CCH pink salmon. The fish lengths were then sorted into ascending order and a random number generator was used to pick a single fish as a starting point. Approximately every other fish, beginning at this starting point, was combusted to determine energy content.

Inter- and Intra- Hatchery and Wild Pink Salmon Comparisons

The central area of PWS was chosen for the comparison of energy content among hatcheries, as samples there had a wide variety of marks, including CCH, SGH, WNH, and WNH +. In addition to the original 25 fish examined, more fish were dissected and dried, and their otoliths were analyzed until there were at least 5 fish per group (CCH, SGH, WNH, and WNH +) at each station.

Data Analysis

A two-factor analysis of variance (ANOVA) was used to compare fish lengths and energy content among stations and hatchery groups. An analysis of covariance (ANCOVA) was used to compare length-weight regression coefficients among stations and hatchery groups. Normal probability plots were used to test for normality and histograms and box plots were used to test for normality, outliers, and homoscedasticity. If the ANOVA or ANCOVA analyses indicated a significant difference among stations or hatchery groups, *a posteriori* comparisons were made with Scheffe's test. The statistical packages used were SYSTAT (Wilkinson et al. 1992) and SAS (SAS Institute 1998).

Hatchery and Wild Comparisons

A two-factor analysis of variance (ANOVA) was used to compare CCH and wild pink salmon lengths and energy content among the six stations in PWS (N1, N2, C1, C2, S1, S2). The two factors were station and mark (i.e. wild fish or CCH fish). The null hypotheses are that there are no differences in fish lengths or energy content between CCH and wild fish or among stations.

An analysis of covariance (ANCOVA) was used to compare log-transformed length-weight regression coefficients among the six stations in PWS and between wild and CCH fish. The dependent variable was the logarithm of weight, the factors used were station and mark (i.e. wild fish or hatchery fish), and the covariate was the logarithm of standard length. Interaction terms were included initially to test for homogeneity of slopes.

Inter- and Intra- Hatchery and Wild Pink Salmon Comparisons

An ANOVA was used to compare four hatchery release groups (CCH, SGH, WNH, and WNH +) and wild pink salmon lengths and energy content at the two central PWS stations (C1 and C2). The factors were station and mark. The null hypotheses are that there are no differences in fish lengths or energy content among the four hatchery groups and wild fish or between the two central PWS stations. An ANCOVA was used to compare the log-transformed length-weight regressions among the four hatchery groups and the wild fish and between the two central stations.

Results

Composition of Catch

Wild and CCH pink salmon dominated the samples at all stations (Figure 3.2). Wild salmon comprised between 28 and 68 % of the samples, and CCH comprised between 16 and 48% of the samples (Figure 3.2 and Table A-3.1). The other hatchery groups that were important components, up to 24%, of the samples at all stations except N1 and S1, were the WNH and WNH + groups. Fish from SGH represented a large portion of the fish at S2 (20%) (Figure 3.2 and Table A-3.1). The fish samples in S1 and near N1 had only two types of thermal marks; whereas, the fish sample near N2 had five types of thermal marks (AFK, SGH, WNH, WNH +, CCH) (Figure 3.2 and Table A-3.1). In five cases, the salmon otoliths could not be clearly identified as thermally marked or the thermal mark could not be identified.

The central area stations had the largest catches of fish and had a wide variety of otolith thermal marks; therefore, additional fish were examined at these two stations for inter-hatchery comparisons. To attain at least 5 fish per hatchery group at the two central stations (C1 and C2), an additional 86 and 37 fish were dissected at C1 and C2, respectively. Wild and CCH fish still comprised the largest portion of the fish sampled at both stations, representing between 27 and 39% (Figure 3.3 and Table A-3.1). The other groups comprised between 4.5 and 14.5% of the samples, except for AFK, which represented less than 3% of the samples (Figure 3.3 and Table A-3.1). Since AFK fish were such a small component of the samples they were excluded, and only wild, CCH, WNH, WNH +, and SGH fish were included in the analyses.

Hatchery and Wild Pink Salmon Comparisons

The two-factor ANOVA indicated there were significant differences in standard lengths among stations and between CCH and wild pink salmon in PWS. On average, wild pink salmon (84.9 mm) were significantly longer than CCH pink salmon (78.7 mm) ($p<0.01$). Average lengths of wild salmon were greater than CCH salmon at all stations except N1 and S1, contributing to the significant ANOVA interaction term (station * otolith mark, $p<0.05$). Pink salmon sampled at S1 (70.5 mm) were significantly shorter than pink salmon sampled at all other stations ($p<0.05$) (Figure 3.4 and Table A-3.2). The longest fish sampled were found at S2 (92.4 mm) and they were significantly longer than fish sampled at all other stations except N2 (88.1 mm) ($p<0.05$) (Figure 3.4 and Table A-3.2). Fish sampled at N2 were significantly longer than those sampled at N1 (77.8 mm) ($p<0.05$) (Figure 3.4 and Table A-3.2). Despite differences in lengths, an ANCOVA revealed no significant differences in the slopes or intercepts of the log-transformed length-weight regressions among the six stations or between CCH and wild pink salmon (Figure 3.5).

Energy content of pink salmon did not differ significantly between wild and CCH fish; however, energy content differed significantly among stations with no geographic pattern (Figure 3.6 and Table A-3.2). Pink salmon sampled at N2 (4,695.5 cal/g) had a significantly higher energy content than fish at other stations, except those fish sampled at S2 (4,601.3 cal/g) and C2 (4,522.3 cal/g) (Figure 3.6 and Table A-3.2). Pink salmon sampled at S2 (4,601.3 cal/g) had the second highest energy content and this was significantly higher than the energy content of fish sampled at C1 (4,401.4 cal/g) ($p<0.01$). Fish sampled at C1 had the lowest energy content observed (Figure 3.6 and Table A-3.2).

Inter- and Intra- Hatchery and Wild Pink Salmon Comparisons

Standard lengths of pink salmon were not significantly different between the two stations sampled in the central area; however, there were significant differences in lengths among the hatchery groups and wild fish (Figure 3.7 and Table A-3.3). CCH pink salmon (76.0 mm) were significantly shorter than all other hatchery groups and the wild pink salmon ($p<0.001$) (Figure 3.7 and Table A-3.3). The SGH pink salmon (95.2 mm) were significantly longer than all other groups except WNH + salmon (87.5 mm) ($p<0.05$). There were no significant differences among the hatchery groups and wild fish or between the two central stations in the slopes or intercepts of the log-transformed length-weight regressions (Figure 3.8).

Energy content of salmon did not differ significantly among hatchery groups and wild salmon; however, pink salmon sampled at C2 (4,552.9 cal/g) had significantly higher energy content than those sampled at C1 (4,368.7 cal/g) ($p<0.001$) (Figure 3.9 and Table A-3.3).

Discussion

Wild and CCH juvenile pink salmon dominated the samples collected in PWS. The predominance of CCH fish over other hatchery fish is a function of the number, size, and dates of fry releases. Cannery Creek hatchery (CCH) released a large group (49.6 million) of relatively small juvenile pink salmon (0.33 - 0.42 g) in late May (May 29) (Table 3.2). Other hatcheries in PWS did not release as many small pink salmon this late in the month. The location of pink salmon hatcheries may also have affected the composition of catches. For example, AFK hatchery is located in the SW corner of PWS, and pink salmon may occupy shallow bays in that area before migrating directly to the GOA, without passing through our study areas.

The number of wild pink salmon fry entering PWS is much lower than the number of hatchery pink salmon released into PWS; however, wild pink salmon comprised the majority of catches in PWS. Wild pink salmon migrate to the ocean over a span of about two months from early April to June; whereas, the majority of hatchery fish are released in May (Cooney 1993). Variable dates and sizes at saltwater entry may explain observed differences in mean lengths among the wild and four hatchery groups of fish.

There was a strong location effect on the size and condition of fish. The rank order of mean fish lengths at the six stations in PWS was similar for both CCH and wild pink salmon ($R = 0.829$). The rank order of the four hatchery groups and the wild salmon mean lengths were also similar between the two stations in central PWS ($R = 0.700$). The condition of pink salmon, as reflected by length-weight regressions and energy content, was similar between CCH and wild fish as well as among all hatchery groups, indicating similar foraging ability. There were differences in energy content among stations indicating that fish were not mixing extensively throughout PWS and that some areas were better for fish growth than others. The similarities in energy content also indicated that fish sampled at one location had been together for some time. Geographical variation in the length and condition of other species, such as sand lance and euphausiids, has also been observed in PWS (Mabry 2000; Snyder and Shirley, in press).

Overall average energy content of pink salmon sampled in PWS in July was approximately 18.99 kJ/g dry weight or 3.88 kJ/g wet weight. This is within the range of energy values found for pink salmon fry in PWS in late May to early June, 1995 of 3.2 - 4.4 kJ/g wet weight (Paul 1997). The highest pink salmon energy values found in 1995 were 4-5 kJ/g wet weight (Paul 1997). This suggests that the pink salmon we sampled in 1998 were not feeding optimally since their energy content was not this high.

Geographic variation in mean length and energy content may be related to physical conditions and/or zooplankton availability in the different areas of PWS. Physical conditions vary with location in PWS due to different combinations of freshwater input, winds, tides, and local topography (Niebauer et al.1994; L. Haldorson, University of Alaska Fairbanks, personal communication). Tides can flush bays in PWS, such as those in Elrington Passage, replenishing the zooplankton (Cooney et al. 1978). Variations in physical conditions can affect the vertical water column structure, and, therefore, primary and secondary production. Primary production is light-limited in the North Pacific; hence, when the water column becomes stable, primary producers are maintained in favorable light conditions, and primary production increases (Gargett 1997). Increased primary production can result in increased zooplankton production and improved feeding conditions for juvenile pink salmon.

The water column at West Naked Island was more stratified and the depth of the chlorophyll maximum was shallower than that of East Naked Island (L. Haldorson, University of Alaska Fairbanks, personal communication). The energy content of juvenile pink salmon sampled west of Naked Island was higher than for pink salmon sampled east Naked Island. The density of herbivorous zooplankton, such as large copepods, larvaceans and cladocerans, was also higher west of Naked Island, 139.7 x $10^3/m^2$, compared to east of Naked Island, 52.0 x 10^3 $/m^2$ (L. Haldorson, University of Alaska Fairbanks, personal communication, Chapter 2). For example, large calanoid copepods were five times denser west than east of Naked Island (Chapter 2). Juvenile pink salmon west of Naked Island may have benefited from high numbers of prey, increasing their energy content.

Pink salmon sampled east of Naked Island had the lowest energy content compared to fish sampled at all other stations in PWS. The water column east of Naked Island had the weakest stratification, deepest chlorophyll maximum, and lowest density of herbivorous zooplankton of all stations sampled. Weak water column stratification east of Naked Island may indicate that zooplankton were more evenly distributed in the water column. This would decrease the effective zooplankton density observed by fish, compared to an area with strong water column stratification, where prey could be concentrated in the upper layer.

Fish sampled at N2, C2, and S2 had the three highest energy densities of stations sampled and also had the top three ranked zooplankton densities, with values ranging from 129.4 to 200.3 x $10^3/m^2$. The density of zooplankton at these three stations was considerably higher than that at the other three stations, 17.3 to 86.6 x $10^3/m^2$. The zooplankton community composition at all stations was dominated by small calanoid copepods. There were geographic differences in the diets of fish, which may have affected their condition (Chapter 2). Fish sampled at N2, C2, and S2, with the three highest energy densities, consumed the two largest prey items found in fish stomachs, large calanoid copepods and larvaceans (Chapter 2). Variation in the availability and/or selection of zooplankton species may contribute to the observed geographic variation in fish energy content.

Juvenile pink salmon consumption of zooplankton in PWS is hypothesized to represent only a minor portion of total available production (Cooney 1993, Chapter 4). Estimates of consumption by pink salmon range from about 0.018 to 6.2% of secondary production to 3% of herbivore production and 10% of macrozooplankton production in PWS (Chapter 4, Cooney 1993). This would indicate consumption of secondary production by salmon should not affect zooplankton abundance; however, not all production in PWS is available to juvenile pink salmon since they utilize shallow bays and nearshore areas (Cooney et al. 1978). Also, juvenile pink salmon consumption of the standing stock of large calanoid copepods in PWS may be substantial (Chapter 4). In areas of weak stratification and low secondary production, planktivory may affect zooplankton densities. Planktivory can cause declines in zooplankton standing stock and, hence, deplete local food supplies (Northcote 1988). Food depletion by planktivores has been demonstrated in both the freshwater and marine environments and may lead to poor fish growth, condition, and survival (Northcote 1988; Gilman 1994; Shiomoto et al. 1997). Potential competitors for zooplankton include fish, such as sand lance, herring, juvenile chum salmon, juvenile pollock and tomcod, and carnivorous zooplankton, such as *Clione* sp., chaetognaths, and hyperiid amphipods (Cooney et al. 1978; L. Haldorson, University of Alaska Fairbanks, personal communication). The utilization of shallow bays by PWS juvenile pink salmon for several weeks during the spring and early summer (Cooney et al. 1978) presents an opportunity for local food depletion in areas of low zooplankton abundance. Areas where pink salmon abundance is high may be areas where food becomes limiting and pink salmon energy is negatively affected (Paul 1997).

Summary

There was a strong location effect on the size and condition of fish. Energy content of pink salmon did not differ significantly between wild and CCH fish; however, energy content differed significantly among stations with no geographic pattern. Energy content of salmon did not differ significantly among hatchery groups and wild salmon; however, pink salmon sampled west of Naked Island had a significantly higher energy content than those east of Naked Island. The differences in energy content among stations indicated that fish were not mixing extensively throughout PWS and that growth conditions varied among stations. The similarities in energy content at one location also indicated that fish at that location had been together for some time.

Low abundance of zooplankton in some areas, such as East Naked Island, may have been responsible for the low energy content observed in pink salmon at some stations. The consistencies in energy content among groups of fish from the same geographic area indicate processes occurring on local scales, such as the effect of stratification on secondary production or local depletion by planktivores, are important in determining the condition of juvenile pink salmon.

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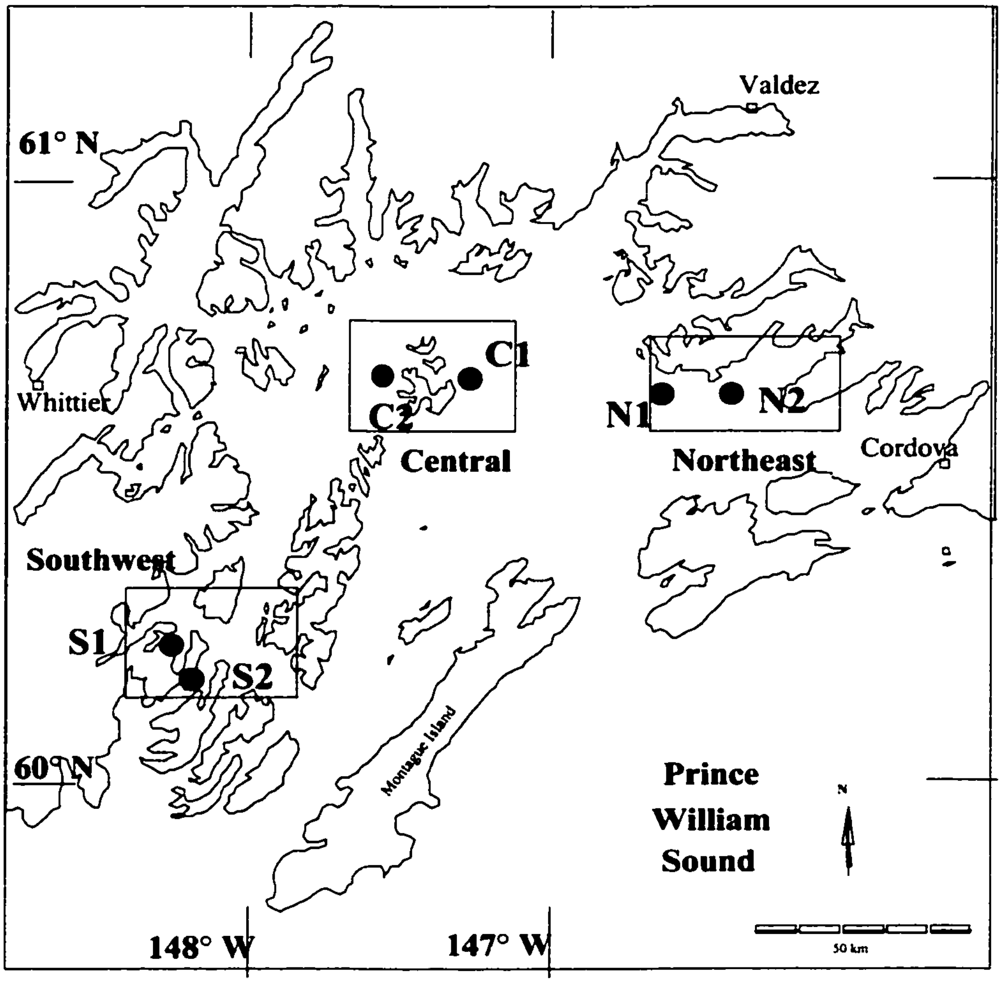

Figure 3.1. The three study areas and six stations sampled in Prince William Sound in July, 1998. The three areas are located in Northeast (N), Central (west central, WC, and east central, EC), and Southwest PWS. Stations N1= Knowles Head; N2= Red Head; C1= East Naked Is.; C2= West Naked; S1= Whale Bay; S2= Bainbridge Passage.

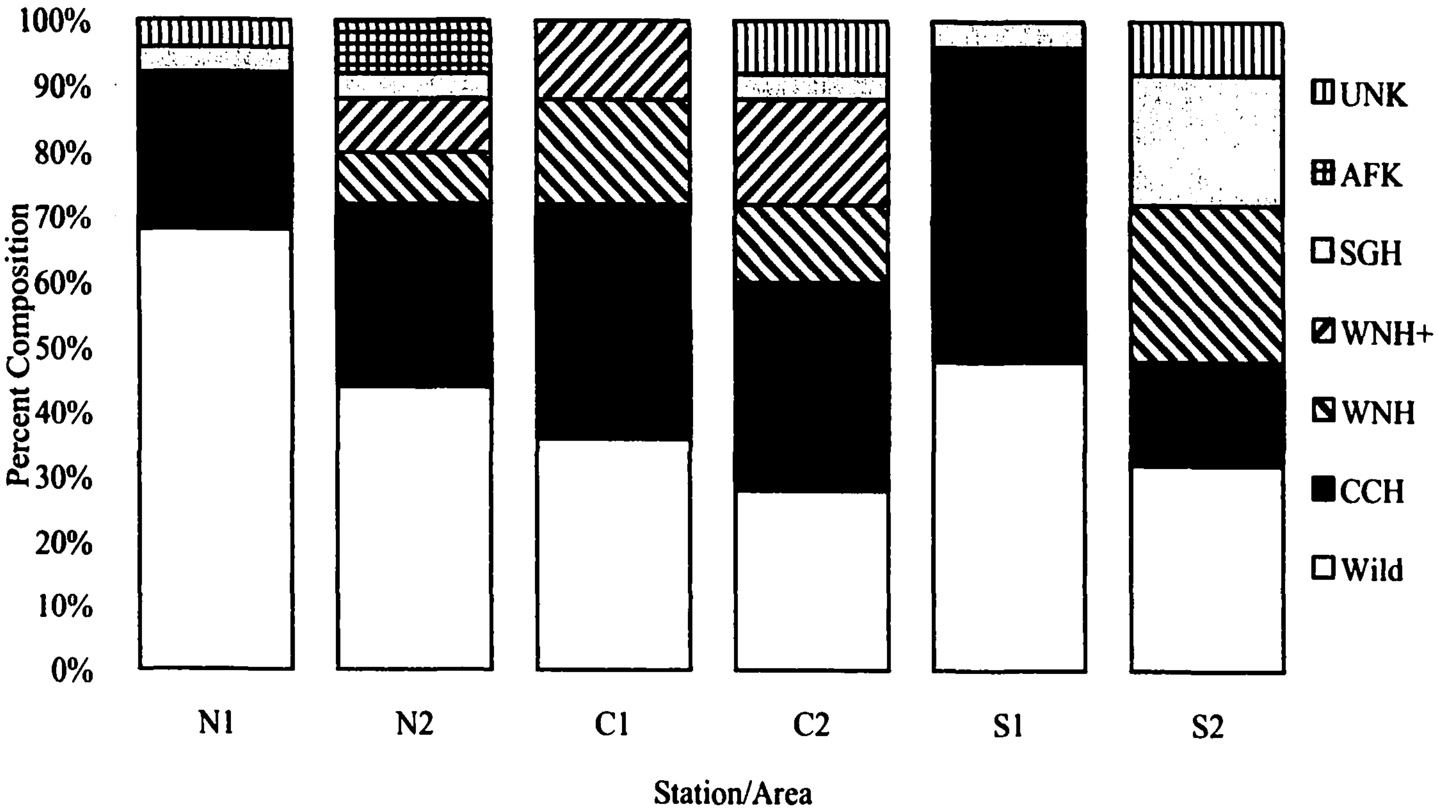

Figure 3.2. Composition of juvenile pink salmon catches in northeast (N1, N2), central (C1, C2), and southwest (S1, S2) PWS. Sample size at each station was 25 fish.
CCH= Cannery Creek Hatchery; WNH= Wally Noerenberg Hatchery; WNH+= WallyNoerenberg Hatchery late release; SGH= Solomon Gulch Hatchery; AFK= Armin Koernig Hatchery; UNK= unknown

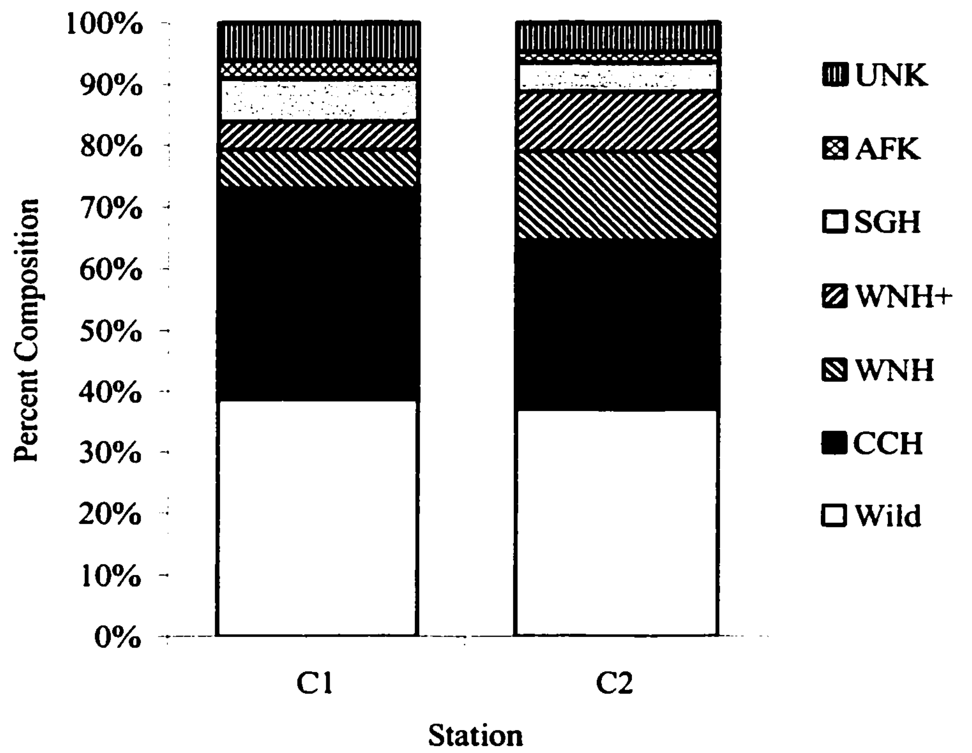

Figure 3.3. Composition of juvenile pink salmon catches in central (C1, C2) PWS. Sample size at each station was 100 and 58 fish for East and West Naked Island, respectively. CCH= Cannery Creek Hatchery; WNH= Wally Noerenberg Hatchery; WNH+= Wally Noerenberg Hatchery late release; SGH= Solomon Gulch Hatchery; AFK= Armin Koernig Hatchery; UNK= unknown.

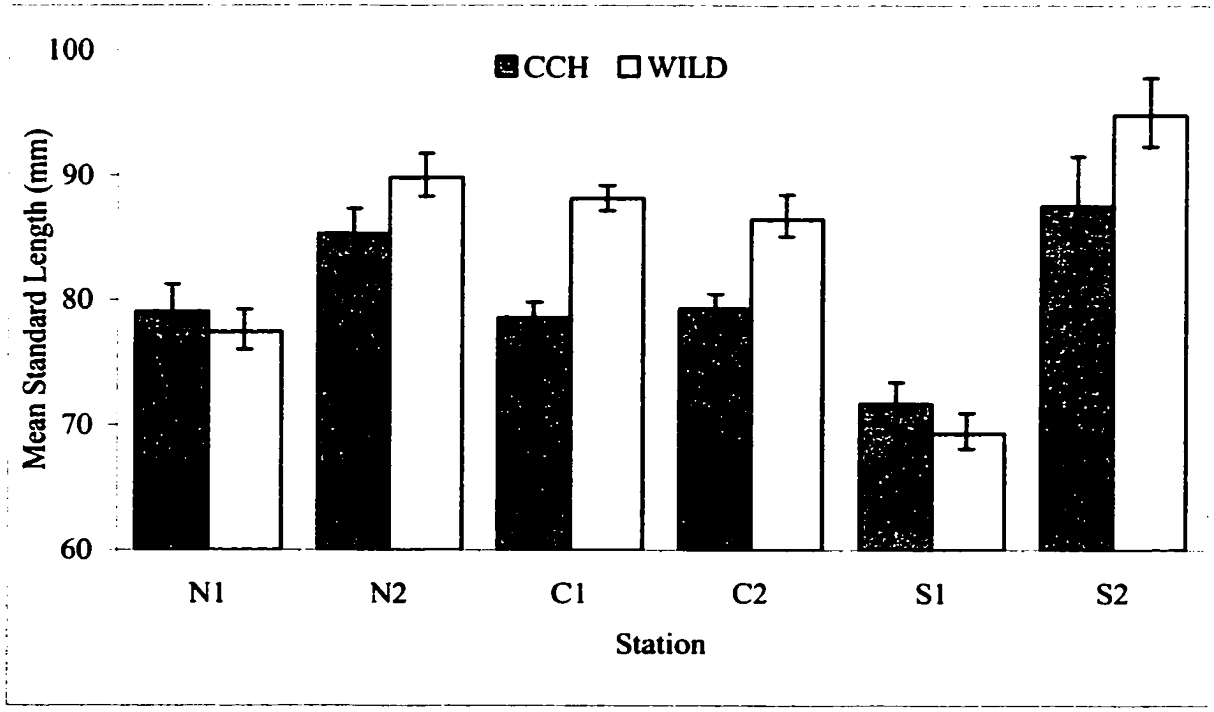

Figure 3.4. Mean standard lengths of juvenile pink salmon catches in northeast (N1, N2), central (C1, C2), and southwest (S1, S2) PWS. Sample sizes at each station varied from 12 to 81. Standard error bars are shown. WILD= wild fish; CCH= Cannery Creek Hatchery fish.

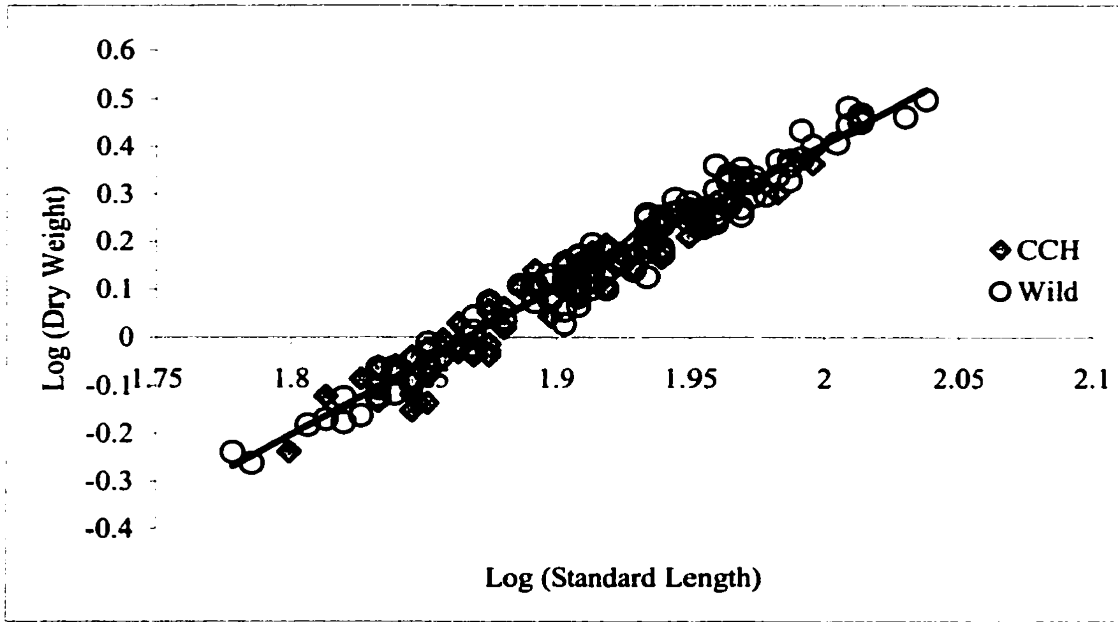

Figure 3.5. Regression of log transformed dry weight as a function of standard length of juvenile pink salmon. Data points include all CCH and wild fish dissected at all 6 stations. There were no significant differences in slopes or intercepts between CCH and wild fish or among stations.

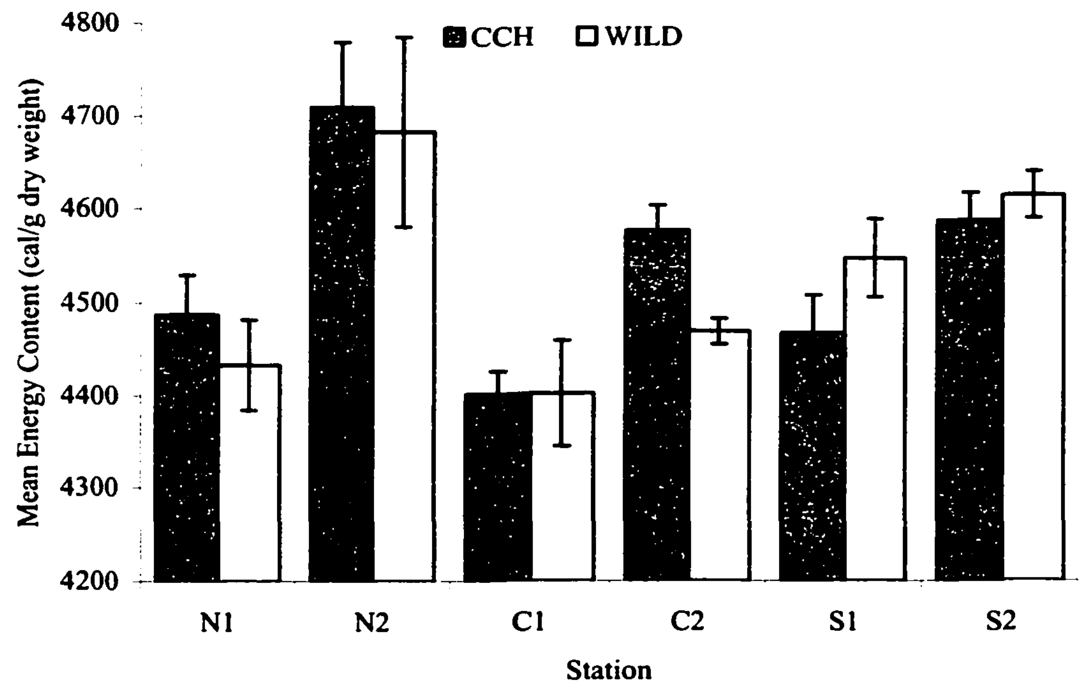

Figure 3.6. Mean energy content of juvenile pink salmon catches in northeast (N1, N2), central (C1, C2), and southwest (S1, S2) PWS. Sample sizes at each station varied from 4 to 8. Standard error bars are shown. WILD= wild fish; CCH= Cannery Creek Hatchery fish.

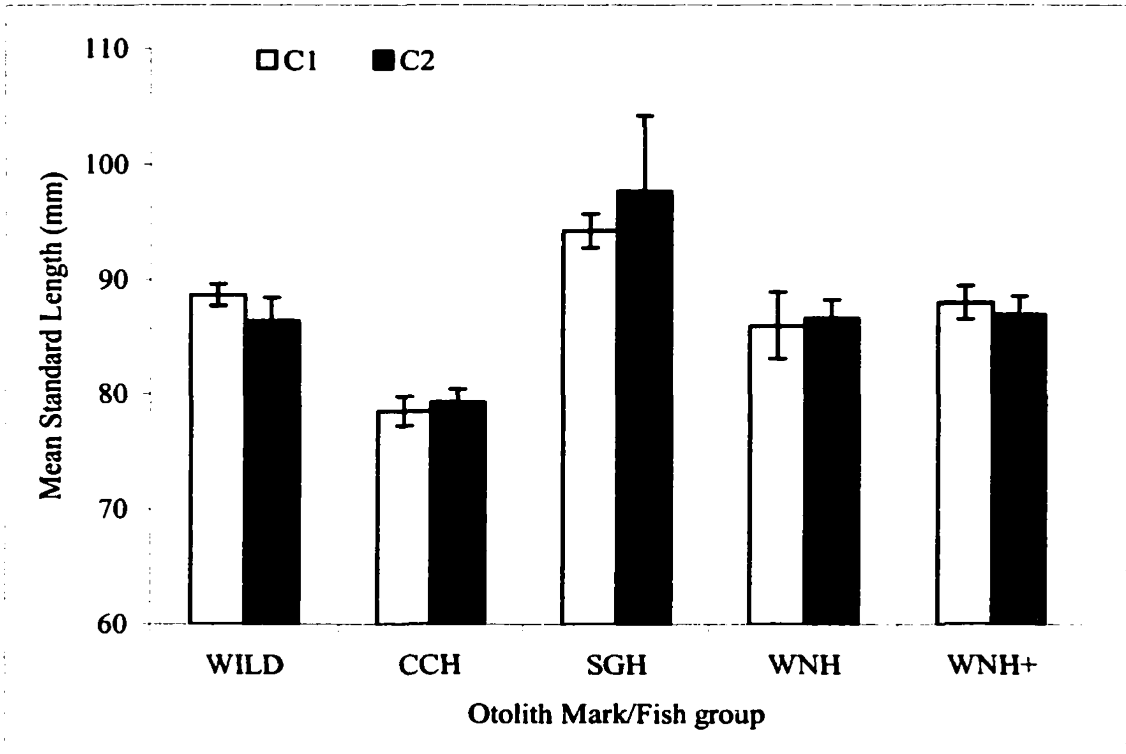

Figure 3.7. Mean standard lengths of juvenile pink salmon catches in central PWS, East (C1) and West (C2) of Naked Island. Sample sizes at each station range from 5 to 38. WILD= wild; CCH= Cannery Creek Hatchery; WNH= Wally Noerenberg Hatchery; WNH+= Wally Noerenberg Hatchery late release; SGH= Solomon Gulch Hatchery fish.

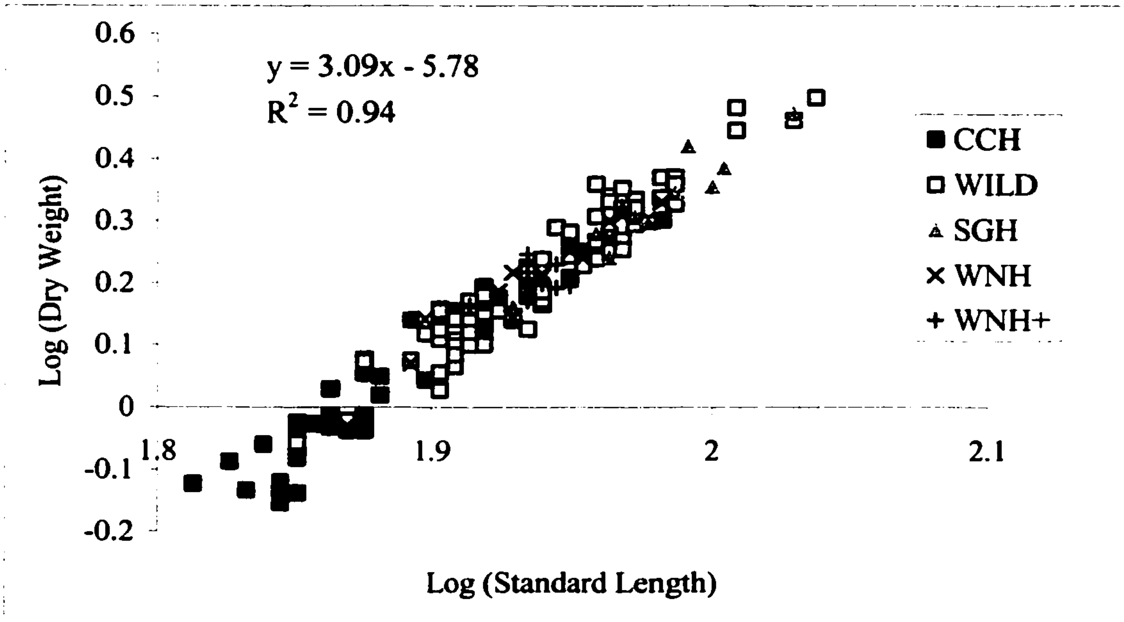

Figure 3.8. Regression of log transformed dry weight as a function of standard length of juvenile pink salmon. Data points include all fish dissected at the two central stations in PWS. There were no significant differences in slopes or intercepts between the two stations or among hatchery or wild groups (wild, CCH, WNH, WHN+, or SGH).

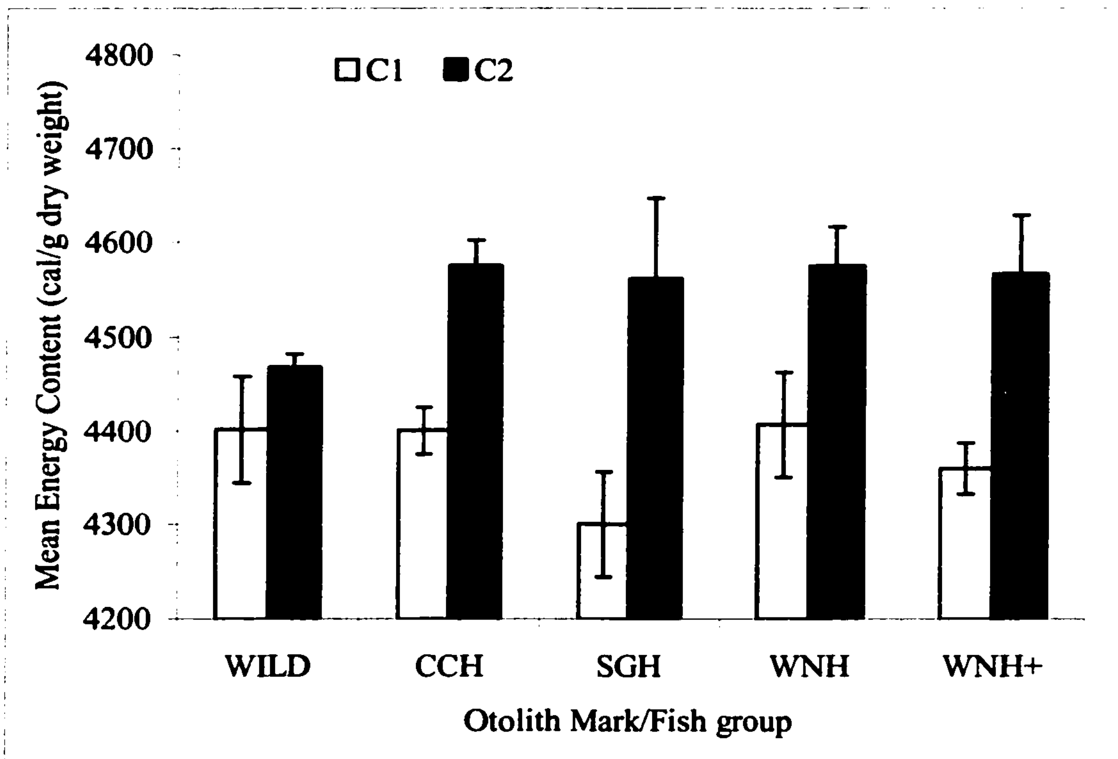

Figure 3.9. Mean energy content of juvenile pink salmon catches at two stations in central PWS. Sample sizes at each station varied from 3 to 9. Standard error bars are shown. WILD= wild; CCH= Cannery Creek Hatchery; WNH= Wally Noerenberg Hatchery; WNH+= Wally Noerenberg Hatchery late release; SGH= Solomon Gulch Hatchery fish.

Table 3.1. Dates and stations where pink salmon were collected in PWS in 1998. Numbers of pink salmon measured, dried, and examined for energy content are reported.

Area	Date	Station	Latitude (deg. min.)		Longitude (deg. min.)		# pink salmon measured and dried	# pink salmon examined for energy content
Northeast	July 15	N1	60	38.89	146	27.69	25	10
Northeast	July 15	N2	60	39.54	146	36.03	25	10
East Central	July 16	C1	60	37.92	147	15.57	105	30
West Central	July 17	C2	60	38.85	147	37.87	61	29
Southwest	July 18	S1	60	13.61	148	10.57	25	11
Southwest	July 19	S2	60	12.06	148	4.75	25	9

Table 3.2. PWS pink salmon release dates, numbers, and sizes in 1998. AFK= Armin F. Koernig Hatchery; CCH= Cannery Creek Hatchery; WNH= Wally Noerenberg Hatchery; SGH= Solomon Gulch Hatchery (Alaska Department of Fish and Game, personal communication).

Hatchery group	Release date	Weight at release (g)	Length at release (mm)	# Released
AFK early	5/7/98	0.45	39.3	66,682,987
AFK late	5/21/98	1.15	52.2	19,142,357
AFK late	5/24/98	1.24	52.2	20,148,891
CCH	5/6/98	0.28-0.39		
CCH	5/20/98	0.36-0.37	*36.4	** 137,571,564
CCH	5/29/98	0.33-0.42		
WNH early	5/1/98	0.49	NA	72,952,272
WNH late	6/1/98	1.53-1.81	NA	30,722,936
SGH	4/23/98	0.42	39	107,691,746
SGH	5/5/98	0.52	43	47,387,864
SGH	5/20/98	0.72	48	40,082,453

*average for all CCH releases
**total for all CCH releases
NA = not available

APPENDIX

Table A-3.1. The numbers and percentages of thermally marked and unmarked pink salmon sampled at six stations in PWS in July, 1998. AFK= Armin F. Koernig Hatchery; CCH= Cannery Creek Hatchery; SGH= Solomon Gulch Hatchery; WNH= Wally Noerenberg Hatchery; ? = indicates a questionable mark; + = indicates a late release group.

			Station				
Thermal mark	N1	N2	C1	C2	S1	S2	Grand total
AFK		2		1			3
AFK 2+			1				1
AFK 2+(?)			1				1
AFK 3+			1				1
CCH	6	7	38	17	12	4	84
SGH	1	1	8	3	1	5	19
WNH		2	7	9		6	24
WNH+		2	5	6			13
Wild	17	11	43	23	12	8	114
unknown	1		7	3		2	13
Sample size	25	25	111	62	25	25	273

Thermal mark	N1	N2	C1	C2	S1	S2	Grand total
AFK	0.00%	8.00%	0.00%	1.61%	0.00%	0.00%	1.10%
AFK 2+	0.00%	0.00%	0.90%	0.00%	0.00%	0.00%	0.37%
AFK 2+(?)	0.00%	0.00%	0.90%	0.00%	0.00%	0.00%	0.37%
AFK 3+	0.00%	0.00%	0.90%	0.00%	0.00%	0.00%	0.37%
CCH	24.00%	28.00%	34.23%	27.42%	48.00%	16.00%	30.77%
SGH	4.00%	4.00%	7.21%	4.84%	4.00%	20.00%	6.96%
WNH	0.00%	8.00%	6.31%	14.52%	0.00%	24.00%	8.79%
WNH+	0.00%	8.00%	4.50%	9.68%	0.00%	0.00%	4.76%
Wild	68.00%	44.00%	38.74%	37.10%	48.00%	32.00%	41.76%
unknown	4.00%	0.00%	6.31%	4.84%	0.00%	8.00%	4.76%

Table A-3.2. Mean standard lengths and energy content values, with sample sizes (n) and standard errors (se) of Cannery Creek Hatchery (CCH) and wild pink salmon sampled at six stations in PWS in July, 1998.

CCH

Station	Average standard length (mm)	n	s.e.	Average energy content (cal/g dry wt)	n	s.e.
N1	79.00	6	2.24	4,487.35	5	42.13
N2	85.29	7	2.03	4,708.87	5	69.46
C1	78.53	38	1.26	4,400.77	5	25.20
C2	79.29	17	1.15	4,575.68	5	26.88
S1	71.67	12	1.72	4,466.55	6	40.13
S2	87.50	4	4.05	4,586.29	4	29.64

WILD

Station	Average standard length (mm)	n	s.e.	Average energy content (cal/g dry wt)	n	s.e.
N1	77.41	17	1.77	4,433.00	8	48.89
N2	89.82	11	1.96	4,682.20	5	101.97
C1	88.14	43	1.05	4,402.01	6	57.42
C2	86.43	23	2.02	4,468.87	5	13.84
S1	69.33	12	1.65	4,546.42	5	41.13
S2	94.88	8	2.97	4,613.31	5	24.95

Table A-3.3. The average lengths and energy content values, with sample sizes (n) and standard errors (se) of pink salmon sampled at the two central stations in PWS in July, 1998. CCH= Cannery Creek Hatchery; SGH= Solomon Gulch Hatchery; WNH= Wally Noerenberg Hatchery; + = indicates a late release group.

C1

Thermal mark	Average standard length (mm)	n	se	Average energy content (cal/g dry wt)	n	se
CCH	78.53	38	1.26	4,400.77	5	25.20
WILD	88.67	42	0.93	4,402.01	6	57.42
SGH	94.25	8	1.49	4,300.63	8	55.96
WNH	86.00	7	2.89	4,406.88	6	56.18
WNH +	88.00	5	1.45	4,359.58	5	27.21

C2

Thermal mark	Average standard length (mm)	n	se	Average energy content (cal/g dry wt)	n	se
CCH	79.29	17	1.15	4,575.68	5	26.88
WILD	86.43	23	2.02	4,468.87	5	13.84
SGH	97.67	3	6.57	4,561.51	3	85.63
WNH	86.67	9	1.55	4,574.96	9	41.13
WNH+	87.00	6	1.51	4,566.60	6	62.22

Chapter 4

Consumption of zooplankton by juvenile pink salmon in Prince William Sound[4]

Abstract

Concerns have developed over the ability of Prince William Sound (PWS) to support the large numbers of hatchery fish that are released annually from hatcheries there. It is possible that planktivory by the historically large number of pink salmon is affecting zooplankton density. The consumption of zooplankton by juvenile pink salmon during their residence in PWS was estimated for 1980 to 1996 using a bioenergetics model. Unlike other studies examining fish consumption in PWS, this model applies fish mortality throughout the period examined, and incorporates physiological parameters to account for costs of metabolism, egestion, and excretion. A pink salmon that grows from 0.26 to 9.6 g wet weight in 93 days in PWS would consume 27.9 g of wet weight. A cohort of juvenile pink salmon would consume between 1.65 and 6.99 x 10^9 g wet weight or 0.01 to 0.05 g $C{\cdot}m^{-2}{\cdot}year^{-1}$. This represents a small fraction of the zooplankton production but potentially a large proportion of the available standing stock in PWS. By assuming a primary production of 100 to 300 g $C{\cdot}m^{-2}{\cdot}year^{-1}$, a transfer efficiency of 20%,

[4] Prepared for submission in Transactions of American Fisheries Society

and secondary production of 20 to 60 g C/m^2, consumption by juvenile pink salmon would be about 0.018 to 0.226% of secondary production. The estimated average daily consumption of large calanoid copepods during this period ranged from 0.421 to 1.78 x 10^{-4} g C/m^2 for 1980 and 1995, or 0.45 to 1.91% of the large calanoid copepods available. Assuming the standing stock of large calanoid copepods remained fixed for 10 days, pink salmon could have consumed about 19% of the available copepods during that time period. Water column stability, planktivory, and pink salmon habitat use may play critical roles in determining zooplankton availability to juvenile pink salmon.

Introduction

Concerns have developed over the ability of Prince William Sound (PWS) to support the large numbers of hatchery fish that are released annually from hatcheries there (Hilborn and Eggers 2000). PWS is an estuary in the North Gulf of Alaska (GOA) that supports large runs of both wild and hatchery pink salmon (Cooney 1993). Juvenile pink salmon occupy the waters of PWS from May to July and scientists have attempted to estimate the effects of their planktivory on zooplankton in the Sound (Cooney 1993).

Pink salmon year class strength is thought to be determined during their first few months at sea (Parker 1966; Peterman 1987; Karpenko 1998). Main determinants of survival during these months include food availability, temperature, and predators (Gilhousen 1962; Peterman 1987; Cooney 1993). Competition for limited food may have negative effects on pink salmon growth. Although competition in the marine environment is difficult to demonstrate, evidence of food limitation can include a change in fish niche dimensions with the introduction or removal of competition, and/or by changes in fish population size, survivorship, growth rate, fecundity, or maturity schedules. For example, the diet of chum salmon was observed to change with the abundance of pink salmon (Tadokoro et al. 1996). Consequences of planktivory can also include changes in plankton abundance, productivity, size structure, and distribution (Northcote 1988).

The mid-1970's was marked by a regime shift in the North Pacific Ocean, after which the Aleutian Low intensified, resulting in increased precipitation and fresh water input in the North Gulf of Alaska (Hollowed and Wooster 1992). Since the density structure of the water column in the GOA is determined primarily by salinity, this increased freshwater input may have resulted in increased stability of coastal North Pacific waters (Gargett 1997; Royer and Weingartner 1999). The increased water column stability may have enhanced primary production by enabling phytoplankton to remain in the euphotic zone (Bigler et al. 1996; McGowan et al. 1998). The total chlorophyll a in the water column of the central North Pacific has increased since 1968 (Venrick et al. 1987). Increased primary production may support increased secondary and fish production. The zooplankton biomass in the subarctic Pacific did increase significantly between 1960-62 and 1980-89 and pink salmon in the N. GOA and PWS have been increasing in numbers since the 1976-77 regime shift (Brodeur and Ware 1992; Beamish et al. 1997).

Increased pink salmon numbers in the N. GOA and PWS may be due to increased zooplankton biomass; however, the weight of pink salmon decreased by about 20% between 1975 and 1995 (Ricker 1995; Bigler et al. 1996). It is possible that planktivory by the historically large number of pink salmon is affecting zooplankton density. For example, pink salmon abundance is inversely related to macrozooplankton biomass and directly related to phytoplankton biomass in the subarctic North Pacific, indicating that planktivory by pink salmon may in fact be affecting zooplankton abundance (Shiomoto et al.1997). Decreased food availability may affect the growth rate of the salmon. Brett et al. (1969) observed that optimal salmon growth occurred at lower temperatures with lower food rations. One hypothesis may be that the higher temperatures after the regime shift (Beamish 1993) caused increased metabolism and energy requirements and, therefore, decreased weight of the salmon, despite increased zooplankton biomass.

Alternatively, it is possible that the decrease in pink salmon weight was due to food-limitation during pink salmon early life history, despite the increase in zooplankton biomass. Coincident to the increase in numbers and decrease in weight of pink salmon was an increase in hatchery production of pink salmon. Annual releases of pink salmon from PWS hatcheries increased dramatically from the mid-1970's and leveled off at about 600 million in the 1990's. Pink salmon fry emerge or are released into PWS in spring and spend the first four months of their lives in shallow bays and the nearshore waters of PWS before moving into the GOA (Cooney et al. 1981; Moulton 1997). It is possible that food limitation during these first months in PWS may result in decreased growth or condition and high mortality. Intense planktivory by pink salmon in these shallow bays may cause declines in zooplankton standing stock, providing evidence of food limitation (Northcote 1988). The increased numbers and decreased weight of pink salmon in the North Pacific may be evidence of food limitation, where there is not enough zooplankton to support the large numbers of pink salmon under the current environmental regime.

Bioenergetic modeling has been used to estimate the amount of zooplankton consumed by fish to test the hypothesis of food limitation in the Great Lakes (Rand et al 1995; Rand and Stewart 1998). This type of model includes the effects of temperature on factors, such as growth rates and assimilation, thereby testing whether temperature or food ration is limiting fish growth. Bioenergetics models are equivalent to mass balance equations that estimate consumption based on temperature-dependent growth, energy expenditures, and waste production. Hewitt and Johnson (Kitchell et al. 1974) have developed a fish bioenergetics model that uses species-specific physiological parameters from recent literature. Data required include initial population numbers, mortality estimates, energetic content, weight, diet, temperature, and the energetic content of the prey. The objective of this paper is to estimate zooplankton consumption by juvenile pink salmon in PWS. To accomplish this objective I: (1) determined the length, weight, and energy content of juvenile pink salmon during their residence in PWS, (2) estimated consumption of zooplankton by PWS pink salmon fry in their first three months at sea from 1985 to 1995, and (3) investigated effects of temperature, diet, and model duration variation on consumption estimates.

Methods and Materials

Study Area

Samples of juvenile pink salmon were collected from three time periods in or close to Prince William Sound (PWS) (Figure 4.1). Five samples of pink salmon were collected from PWS hatcheries at the time of release in May 1998. The second set of samples was collected from two stations within three areas of PWS, July 14-18, 1998. The third sampling period was conducted at two stations near Cape Puget in the northern GOA (outside the southwest corner of PWS), August 1, 1998 by the Ocean Carrying Capacity project (OCC). These samples and the processing of these samples is described in Chapter 1.

Bioenergetics Model

The Hewitt and Johnson (Hanson et al. 1997) model was used to estimate pink salmon fry consumption in PWS for 93 days (May 1 to August 1) from 1980 to 1996. The model estimates how much a fish would need to consume to achieve the observed growth rate while accounting for respiration, egestion and excretion. Consumption is calculated on a daily basis and as a specific rate ($g \cdot g^{-1} \cdot day^{-1}$) (Hanson et al. 1997, Appendix A-4.1 and Table A-4.2). Consumption is calculated as a proportion of maximum consumption (Cmax) modified by a temperature-dependence function. The temperature-dependence function describes the product of two curves, one in which the proportion of Cmax increases with increasing temperature, and one in which, after some cutoff temperature, the proportion of Cmax decreases with increasing temperature (Hanson et al. 1997). Maximum consumption is calculated as a function of fish weight and an allometric mass function (Hanson et al. 1997). The allometric mass function describes a curve in which Cmax increases with fish weight (Hanson et al. 1997, Appendix A-4.1 and Table A-4.2).

Respiration is calculated utilizing an allometric weight function, a temperature-dependence function, and an activity multiplier (Hanson et al. 1997, Appendix A-4.1 and Table A-4.2). The temperature-dependent function describes a curve in which respiration rate increases exponentially with temperature (Hanson et al. 1997).

Egestion is calculated as a proportion of consumption, modified by a function that accounts for the proportion egested as a function of water temperature and ration (Hanson et al. 1997, Appendix A-4.1 and Table A-4.2). Excretion is calculated as a proportion of what is consumed less the amount of energy egested. The calculations of egestion and excretion account for the proportion of prey that is indigestible (Hanson et al. 1997). The activity multiplier is a function of swimming speed, which is a function of fish mass and water temperature below 25 degrees C.

Physiological parameters for adult pink salmon, provided in the software for this model (Fish Bioenergetics 3.0), were used since information on juvenile pink salmon is limited; therefore, results may be biased (Hanson et al. 1997, Appendix A-4.1, Table A-4.2). Data needed to run the model include: temperature, population numbers, mortality, energetic content, weight change, diet and prey energetic content.

Consumption was calculated as grams of prey consumed over the 93 days that pink salmon reside in Prince William Sound. To convert consumption to grams of carbon consumed per square meter of surface, consumption was divided by the area of Prince William Sound (8.8×10^9 m^2) and multiplied by 0.057 (assuming 0.057 gC/1.0 g wet weight).

Temperature

The model was run using 6, 8, 10, and 12 degrees Celsius for days 1, 32, 62, and 93 for all years. Pink salmon fry are usually found near the surface, therefore estimates of water temperature in the upper 1 m of the water column were used for the model (Cooney et al. 1995). The water temperature is typically about 4 °C in early April and warms to 12 °C in the upper 1 m of the water column by August (Cooney et al. 1995)

(Table 4.1). Within the bioenergetics model, temperature is incremented by linear interpolation. The model was also run with a minimum (4, 6, 8, 10 degrees C for days 1, 32, 62, 93) and maximum (8, 10, 12, 14 degrees C for days 1, 32, 62, 93) temperature regime to examine the effect of temperature variation on consumption estimates. These temperature regimes were chosen because sea surface temperatures in the N.GOA from April to June vary by approximately plus or minus 2 degrees Celsius (Cooney et al. 1995). Temperature data is available for a station in the N.GOA near the mouth of Resurrection Bay (GAK 1). Water temperature at the surface was measured four times between May and August, 1994 (Table 4.2). These temperatures are very similar to the overall averages used in the model. Daily water temperatures at 20 m depth were also available from mooring data at GAK 1 in 2000 (Figure 4.2, Table A-4.3, T. Weingartner, University of Alaska Fairbanks, personal communication). Temperatures were very similar to the overall averages used in the model and are within the minimum and maximum temperature regimes examined. This daily temperature data was utilized in the model for one year (1995) to examine the effects of daily temperature variation on overall fish consumption.

Population Numbers

Numbers of fry released from hatcheries have been documented (Sharp et al. 2000), but the numbers of wild fry entering PWS are not well known. To estimate the number of wild fry entering PWS, the survival rate of hatchery fish from the time of release to the time of return was applied to the wild fish returns (Table 4.3). Wild return numbers (Morstad et al. 1996; T. Joyce, Alaska Department of Fish and Game, personal communication) were divided by hatchery fish survival to estimate the number of wild fry entering Prince William Sound in the previous year. Wild fry numbers were then added to hatchery fry release numbers to get the estimate of total fry for each year. The mortality of wild pink salmon in 1995 was altered by plus and minus 10% to estimate a range of wild fry numbers that could enter PWS (Table 4.4).

Mortality

An average mortality value of 69% was used for the first 40 days and then a value of 0.6% per day was used for the last 53 days (26.87). These values are based on mortality estimates from British Columbia (BC), since there are no available estimates for PWS. Bella Coola River pinks experienced 59 to 77% loss of the initial population in their first 40 days at sea and then lost an average of 0.4 to 0.8% of the population per day after that (Parker 1966). Fraser River pinks and central BC coast pinks experienced mortalities of 90 and 81% respectively in their first four months of life at sea (Parker 1966; Walters et al.1978). Mortality rates within the model were varied by plus or minus 10% to examine the effects on consumption. The high mortality rates utilized were 75.9% for the first 40 days modeled and 0.66%/day for days 41-93 (29.131%). The low mortality rates used were 62.1% for days 1-40, and 0.54%/day for days 41-93 (24.54%).

Weight of Pink Salmon

The initial weight of pink salmon used for this model was 0.26 g and the final weight was 9.6 g wet weight. Weight estimates were based on wet weights determined in the laboratory in combination with literature values and growth rates (Table 4.5). The average weight of PWS juvenile pink salmon sampled upon release from hatcheries was 0.289 g (Chapter 1); however, this sample was not necessarily a random sample. Pink salmon have also been reported to weigh 0.2 – 0.3 g when they enter the sea (Pritchard 1944; LeBrasseur and Parker 1964; Cooney et al.1978; Parker and Massa 1993); therefore, a value of 0.26 g was used in the model. To determine the final weight, a growth rate of 4% body weight per day was applied (Chapter 1, Willette et al. 1994) and resulted in a value of 9.6 g wet weight by August 1. The weight of pink salmon sampled near Cape Puget in August was not utilized for the final weight in the model, since it is not known how long those fish were outside of PWS.

Energetic Content of Pink Salmon

The energy content of pink salmon used in the model was 4.171 kJ/g wet weight for all days. This is an average value of all the pink salmon sampled in 1998 (Chapters 1 and 3, Table 4.5). The energy content of the fish was not varied over the 93 days modeled because the observed energy content of fish did not increase with time in 1998. The average energy content of pink fry measured upon release in 1998 was 4.102 kJ/g wet weight, which corresponds with previous studies: 3.2-4.4 kJ/g wet weight (Paul and Willette 1997) (Table 4.5). In July 1998, juvenile pink salmon in PWS had an average energy content of 3.883 kJ/g wet weight (Table 4.5). Pink salmon sampled near the SW corner of PWS (Cape Puget) in August had an average energy content of 4.359 kJ/g wet weight. The average value was, therefore, utilized in the model (4.171 kJ/g wet weight).

Diet

The diet of juvenile pink salmon expressed as percent biomass was utilized in the bioenergetics model. The analysis of stomach contents of pink salmon sampled in PWS, July 1998 was used for model days 62-93 (July) (Table 4.6, Chapter 2). The main prey items were large (>2.5 mm) calanoid copepods, cladocerans, and larvaceans, which comprised 24.9, 23.5 and 19.5% weight, respectively. Other prey items consumed by the pink salmon included barnacle nauplii and cyprids, insects, and small calanoid copepods (Table 4.6). Prey items that comprised less than 5% weight were grouped into the "other" category and included prey items such as polychaetes, invertebrate eggs, and unidentifiable crustaceans (Table 4.6). To estimate the percent biomass each prey item comprised in fish diets, prey weights were estimated from laboratory and literature values (Table 4.7). The diet of pink salmon prior to model day 62 was estimated from the literature. Cooney et al. (1978) reported the average number of prey consumed by juvenile pink salmon in PWS in May and June. These were converted to biomass and percent biomass using the same methods and prey weights as for the July 1998 samples (Table 4.7).

The model was also run seven separate times with varying fish diets for a typical year (1990) to examine the effects on consumption. The model was run with fish diets that consisted only of large calanoid copepods, larvaceans, cladocerans, insects, nauplii, euphausiids, or hyperiid amphipods.

Prey Energy Content

Energy content of prey items utilized in the model were acquired and averaged from literature values (Table 4.6). The energetic content of prey items varies among seasons (Harris 1985; Dawirs et al.1986; Davis et al. 1998); however, for simplicity and due to lack of available information, the energy content of prey items was assumed to be constant for the months modeled. Prey items comprising a small percentage of pink salmon diets (polychaetes, unidentified crustaceans, and invertebrate eggs) were grouped together and labeled "other". The caloric content of this "other" category was calculated as an average of caloric values of the different prey items (Table 4.6). The proportion of each prey group that was indigestible was estimated from the literature where possible, otherwise, it was assumed that 10% of the prey was indigestible (Table 4.6).

Period Modeled

The model was initially run from May 1 to August 1, 93 days. May 1 is the approximate median date that fish are released from PWS hatcheries. It was found that pink salmon move out onto the GOA shelf beginning at least in mid-July, but can still be found near PWS on the shelf in October (Chapter 1); therefore, August 1 was chosen as an approximate end date of pink salmon residence in PWS. The number of days modeled was altered by plus and minus 10 (83 and 103 days) to examine the effect on consumption for a typical year (1990). The model was also run for 120 days (for the 1990 year class), the number of days that has been previously reported as the residence time of pink salmon in PWS (Cooney and Brodeur 1998). The values of water temperature, diet of fish, prey energy density, and predator energy density for the three models were kept the same as for day 93. The same growth rate (4% body weight per day) utilized in the 93 day model was utilized to estimate a final fish weight for days 83, 103, and 120 as 6.5, 14.2, and 27.7 g, respectively. An initial mortality rate of 66% was utilized for the first 40 days modeled. A mortality rate of 0.6%/day was utilized after day 40, and resulted in mortality estimates of 22.4, 31.1, and 37.8 to days 83, 103, and 120, respectively.

Results

The average consumption by juvenile pink salmon during their first three months at sea was 5.07×10^9 g wet weight. Estimates varied from 1.65×10^9 to 6.99×10^9 g wet weight or from 0.0107 g C/m^2 in 1980 to 0.0453 g C/m^2 in 1995 (Figure 4.3 and Table 4.8). This was expected since the estimated number of juvenile pinks in Prince William Sound was lowest in 1980 and highest in 1995. Consumption was greater than 6.0×10^9g, from 1988 to 1996, with the exception of 1994 when the number of pink salmon in PWS was lower (Figure 4.3 and Table 4.3). Hatchery fish were responsible for the majority of consumption from 1985 to 1996, and wild fish consumed more food in 1980-84 (Figure 4.3 and Table 4.8).

Large calanoid copepods comprised the largest proportion of the pink salmon diet and it was estimated that 0.66×10^9 g wet weight in 1980 to 2.8×10^9 g wet weight in 1995 of calanoid copepods were consumed in PWS (Figure 4.4). Larvaceans comprised the second largest proportion of juvenile pink diets, 0.40 to 1.69×10^9 g wet weight. Cladocerans were also important prey items. Pink salmon consumed 0.21×10^9 to 0.88×10^9 g wet weight in 1980 and 1995, respectively (Figure 4.4).

Varying the temperature regime by plus or minus 2 degrees Celsius resulted in different consumption estimates. Consumption estimates were higher for the warmer temperature regime and estimates ranged from 4.451×10^9 g to 5.298×10^9 g for the coolest and warmest temperature regimes, respectively (Figure 4.5). Varying the temperature regime changed the consumption estimate by plus 10.0% or minus 7.6% from the average temperature regime.

Utilization of the daily mooring temperature data from GAK 1 in the N. GOA, for the 1995 year class resulted in very little change of the consumption estimate. The consumption estimate, using the mooring data was 2% lower than that of the original model. This estimate falls in the range of consumption estimates calculated using the minimum and maximum temperature regimes.

Increased fry-to-adult-survival rates of wild fish compared to hatchery fish, resulted in fewer wild fry entering PWS (Table 4.4). Overall consumption by juvenile pink salmon in PWS was, therefore, reduced when fewer wild pink salmon entered PWS (Table 4.9). When wild pink salmon survival was altered by plus or minus 10%, the overall consumption in PWS changed by plus or minus 3% (Table 4.9). Varying the survival of wild fish altered the proportion of zooplankton consumed by hatchery versus wild pink salmon fry only slightly. Wild pink salmon consumption represented 27.6% of the consumption in the original model; this was reduced by about 2% when wild salmon survival was altered by plus or minus 10% (Table 4.9).

Consumption estimates are affected by changes in the mortality rate of pink salmon. Varying the mortality rate of pink salmon by plus or minus 10% resulted in a plus or minus 20% change in the estimated consumption (Table 4.10).

Varying the length of time also affected consumption estimates. The model was run for 83, 103, and 120 days for the 1990 year class. Consumption estimates in the 83 day model were 30% and 35% (individual and population estimates, respectively) lower than consumption estimates for the 93 day model (Figure 4.6). Individual and population consumption estimates were 53.5 and 40.7% higher in the 103 day model compared to the 93 day model. The 120 day model resulted in much higher consumption estimates than those from the 93 day model, plus 211 and 162%, for the individual and population estimates, respectively (Figure 4.6).

Consumption estimates for the 1990 year class were affected differentially by varying fish diets (Figure 4.7). If pink salmon consumed only large copepods, to achieve the same growth rate as with a multi-species diet, they would consume 14.6% less food; whereas, if fish consumed only larvaceans the consumption estimate was virtually the same as with the multi-species diet (Figure 4.7). Consumption estimates decreased if fish consumed only insects (decrease of 28.6%) or euphausiids (decrease of 5.4%). When pink salmon diet was altered so that only cladocerans, nauplii, or hyperiid amphipods were consumed, consumption estimates increased by 32.7, 66.8, and 13.5% from that of the multi-species diet (Figure 4.7).

Seasonal variation in consumption was examined by plotting the consumption by individual fish over the 93 day period for a typical year, 1990 (Figure 4.8). Consumption by an individual juvenile pink salmon over the 93 day period modeled increased from less than 0.1 g to about 0.7 g per day (Figure 4.8). Large calanoid copepods comprised the majority of the zooplankton consumed for the first 40 days, after which consumption of other prey items increased. Larvaceans and large calanoid copepods represented almost all prey consumed between model days 35-55. Larvaceans, cladocerans, and large calanoid copepods comprised important components of the zooplankton consumed in the last 45 days (Figure 4.8).

Seasonal variation in consumption by the whole population in a typical year, 1990, was examined (Figure 4.9). Consumption by the population in 1990 increased from 3.25×10^7 g per day to 12.59×10^7 g per day by the end of the 93 day period (Figure 4.9). Consumption by pink salmon increased during the 93 days, despite the decrease in fish numbers with time, because fish are released from the relatively high initial mortality rate (69% over days 1-40) and because individual fish consumption (grams of wet weight) increases with time and fish size (Figures 4.8 and 4.9). The composition of prey consumed by the cohort of salmon followed a similar pattern to that for the individual fish consumption. Large calanoid copepods were the main prey consumed; however, small calanoid copepods, insects, and larvaceans represented about 1/3 of the prey consumed in the first 35 days modeled (Figure 4.9). Larvaceans and large calanoid copepods were essentially the only prey consumed on model days 35-55. After day 55, a large weight of cladocerans were also consumed (Figure 4.9).

Discussion

Estimated consumption by juvenile pink salmon in PWS was highest after 1987 due to the higher number of hatchery releases. Hatchery fish consumption increased in the early 1980's and was twice as high as wild fish consumption in the late 1980's to 1990's. These consumption estimates may not be completely accurate, however, they are informative and interesting for comparative purposes.

An average energy content of pink salmon, 4.171 kJ/g wet weight, was utilized in the model, which is in the range of values, 3.2-5.2 kJ/g wet weight, found for PWS pink salmon, May 31- June 2, by Paul (1997). The energy content and condition of juvenile pink salmon, however, can vary geographically (Parker and Massa 1993; Perry et al.1996; Paul 1997; Chapters 1 and 3). Variables that could affect the condition and energy content of fish include temperature, salinity, interspecific and intraspecific competition, and the types of prey available (Brett et al. 1969; Smith et al. 1986; Parrish and Mallicoate 1995). Consumption estimates could, therefore, also vary geographically within PWS, but these differences were ignored for simplicity when running the model.

The diet of pink salmon can also vary geographically, seasonally, and annually in PWS (Chapters 1 and 2). In this study the diet of juvenile pink salmon in PWS for May and June was estimated from the literature, and the diet for July was estimated from stomach analysis. Juvenile pink salmon consumed primarily large calanoid copepods, cladocerans, and larvaceans in July. Variation among years or areas was not considered for lack of data; however, consumption estimates may be affected by differences in diet.

Pink salmon consumption estimates may also be affected by water temperature (Brett et al. 1969) and zooplankton availability (Cooney et al.1995). Temperature not only affects the amount of food salmon consume, it also affects their emigration timing from natal streams into PWS (Cooney et al.1995). During cold years, pink salmon fry appear to emigrate later than in warmer years (Cooney et al.1995). The earlier emigration of pink salmon fry in warmer years corresponds closely with the zooplankton peak (settled volume) which typically occurs in May (Cooney et al. 1995); therefore, temperature may determine whether pink salmon enter PWS at a time during peak or declining zooplankton biomass. Temperature, salinity, currents, and food availability also affect pink salmon residence time in PWS and, therefore, may affect the total amount of zooplankton consumed in a summer (Cooney et al. 1981).

Water temperature was not varied annually in the model due to lack of data. However, historical average sea surface temperatures in PWS for April to June 1965-91, vary by plus or minus two degrees and this range encompasses actual daily temperatures recorded in the NGOA from May 1 to August 1, 2000 (Cooney et al. 1995; T. Weingartner, University of Alaska Fairbanks, personal communication). The temperature regimes used in the model varied by plus or minus two degrees Celsius. Actual daily mooring temperature data collected in 2000 and surface temperatures recorded in 1994, indicate that the temperature regimes used in the model are representative of the possible temperature regimes that juvenile pink salmon encounter.

The resulting consumption estimates, using the minimum and maximum temperature regimes, varied by 10% to 7.6%.

It is difficult to find estimates of wild pink salmon survival rates in PWS and it is possible that they do not have the same survival rates as hatchery fish. I estimated the number of wild fry entering PWS from the number of returning adults and hatchery survival rates. If wild salmon survival rates were higher than those of hatchery salmon, there would have been fewer wild salmon entering PWS, and a resultant decrease in consumption estimates. Mortality of fish may also vary from the estimates I utilized within the model during the 93 day period. Higher mortality rates would also result in a decrease in consumption estimates.

Zooplankton density is strongly related to water column stability and light availability in PWS (L. Haldorson, University of Alaska Fairbanks, personal communication). Water column stability varies among areas and years in PWS and when the water column is more stable, zooplankton density is higher (L. Haldorson, University of Alaska Fairbanks, personal communication). Water column stability, therefore, affects the amount of zooplankton available to pink salmon. Zooplankton composition also changes with seasons, thereby, affecting what prey types are available to pink salmon (Cooney et al., in press). In all months, small calanoid copepods comprise the majority of zooplankton numbers in the upper 50m of PWS (Cooney et al., in press). The densities of large calanoid copepods, such as *Neocalanus* spp. and *Calanus marshallae*, increase in May and June, and decrease by July and August (Cooney et al., in press). Pteropods, larvaceans, and cladocerans are important components of the zooplankton in

June and July in PWS (Cooney et al., in press). Consumption by individual pink salmon and their cohorts reflected these changes in zooplankton composition. Primarily large calanoid copepods were consumed in May; whereas, in June and July, larvaceans and cladocerans were major components of the prey consumed by juvenile pink salmon.

Pink salmon diet was altered in the model for the 1990 year class to examine the effects on consumption. If pink salmon were constrained to consuming only one prey item, consumption estimates varied according to the energy density of the prey items. Consumption of high calorie prey items resulted in lower consumption estimates; whereas, consumption of low calorie prey items increased consumption estimates. High calorie prey items included large calanoid copepods (3,810.7 J/g wet weight), insects (4,531.8 J/g wet weight), euphausiids (3,454.8 J/g wet weight), and larvaceans (3,287.8 J/g wet weight). Low calorie prey items included cladocerans (2,513.5 J/g wet weight), nauplii (2,045.3 J/g wet weight), and hyperiid amphipods (2,906.0 J/g wet weight).

The bioenergetics model has over 25 parameters and inputs that could affect the estimates of consumption. Sensitivity analyses, however, indicate that perturbations of all parameters, except prey energy content and the proportionality constant (P), do not significantly affect consumption estimates (Beauchamp et al. 1989). The proportionality constant is the proportion of maximum consumption that a pink salmon consumes based on input data (Hanson et al. 1997). A 10% deviation in the nominal parameter value for the proportionality constant altered consumption estimates by -28 and +35%, and the same deviation in the nominal value of prey energy density altered consumption estimates by -10 and +12% (Beauchamp et al. 1989). Also, it is apparent from this study that the mortality rate of pink salmon and the duration of the period modeled can also significantly affect the consumption estimates. The energy content of prey items varies with season, however, it was assumed to remain constant for the 93 days modeled in this study. Also, when data was not available, average values or adult energy values were substituted for larval stages of prey or prey with unknown energy values. Further studies are needed to examine changes in energy content of prey items with season and the proportion of prey that is digestible.

According to the bioenergetics model a pink salmon that grows from 0.26 to 9.6 g wet weight in 93 days in PWS, would consume 27.9 g of wet weight. This is similar to Cooney's (1993) estimate for pink salmon that reside in PWS for four months (36.4 g). If the numbers of fry entering PWS and their mortality is considered, population consumption ranges from 1.65×10^9 to 6.99×10^9 g wet weight or 0.0107 - 0.0453 g C/m^2. Cooney (1993) estimated that consumption by 371 million surviving and 829 million non-surviving salmon would be about 45.9×10^9 g wet weight, which is over six times higher than the estimate in this study. If the bioenergetics model is run with an initial population of 1.2 billion pink fry and final fish weight of 9.1 g, as was used by Cooney (1993), the estimated consumption is 9.4×10^9 g wet weight. This estimate is five times lower than that estimated by Cooney (1993).

Disparities between consumption estimates in this study and Cooney's (1993) are due to differing assumptions made about residence time, pink salmon numbers, mortality, and gross growth efficiencies. Cooney (1993) assumed that pink salmon reside in PWS for 4 months; whereas, in this study, the model was run for only 3 months (93 days). Increasing the residence time of pink salmon in PWS in the bioenergetics model resulted in an increased estimate of consumption, assuming that fish continue to grow at the same rate. If pink salmon reside in PWS for 120 days and grew to 27.67 g, they could potentially consume 162% more zooplankton than if they resided there for 93 days and grew to 9.6 g.

Other differing assumptions between this and Cooney's (1993) study include the numbers of pink salmon and their mortality. Cooney assumed there were 1.2 billion hatchery and wild salmon entering PWS; this is higher than any estimate utilized in this study. If more pink salmon enter PWS, they will consume more zooplankton. Cooney (1993) applied all the mortality at the halfway point of residence time. The bioenergetics approach used in this study allows mortality to be applied and consumption to be calculated daily throughout the residence time in PWS. The mortality rate used by Cooney (1993) was much lower than the one used in this study. Cooney (1993) estimated that 439 million pink salmon would be lost to predators; whereas, using the mortality rates in this study, 970 million salmon would be lost to predators. If the bioenergetics model is run with the lower mortality rate (2.96 total mortality), over 120 days, with an initial population of 1.2 billion salmon, with an initial fish weight of 0.26 g, and a final weight of 9.1 g, consumption by pink salmon would be 35.6×10^9 g wet weight. This was more comparable to Cooney's (1993) estimate of 45.9×10^9 g wet.

Another reason for the disparities between this study and that of Cooney's is the assumption about gross growth efficiency. Cooney (1993) also assumed a gross growth efficiency of 25%; whereas, the model used in this study determines consumption based on data input. The advantages of the bioenergetics model over the use of a single gross growth efficiency are that estimates of consumption are calculated on a daily basis, while accounting for water temperature, metabolism, fish weight, prey energy density, fish diet, egestion, and excretion.

The importance of consumption estimates can be appreciated by comparing them to the amount of production that is available in PWS. Consumption estimates in this study represent only 0.011 to 0.033% of the primary production available in a nontropical, coastal shelf area per year (100 to 300 g $C \cdot m^{-2} \cdot year^{-1}$) (Ryther 1969; Jones 1984; Pauly and Christensen 1995,). Assuming a transfer efficiency of 20%, secondary production is approximately 20 to 60 g C/m^2 and consumption by juvenile pink salmon is about 0.018 to 0.226% of secondary production (Jones 1984).

These estimates of consumption in PWS assume that the primary and secondary production and pink salmon are distributed evenly throughout PWS and the period modeled. However, juvenile pinks only reside in PWS for 3 to 4 months and they may not be using the entire Sound, since aggregations of juvenile pinks are found in bays (Cooney et al. 1978). Zooplankton production and composition also varies with water column stability and season (L. Haldorson, University of Alaska Fairbanks, personal communication; Cooney et al., in press, Gargett 1997). This may result in localized depletion of food resources, and alter the amount of energy consumed by pink salmon (Cooney et al. 1978; Paul 1997). If only a 100 m wide area along the shorelines of Prince William Sound is considered, 3.2×10^8 m^2 (Cooney et al. 1978), the proportion of zooplankton consumed by pink salmon would be considerably higher, 0.90 g C/m^2, or 0.49 to 6.22% of the secondary production.

Plankton data sampled with a bongo net at each station where salmon were captured indicate that pink salmon may be consuming a small proportion of the available standing stock of cladocerans and larvaceans, but could be consuming a substantial proportion of the standing stock of large calanoid copepods. By assuming that these plankton samples are representative of typical plankton composition and that the zooplankton is available to the pink salmon, comparisons to the consumption estimates can be made. Consumption estimates of primary salmon prey can be averaged over the same time period that the plankton samples were collected (July 14-20) (Figure 4.10). The average daily consumption of large calanoid copepods during this period ranged from 0.421 to 1.78 x 10^{-4} gC/m^2 for 1980 and 1995, or 0.45 to 1.91% of the large calanoid copepods available (L. Haldorson, University of Alaska Fairbanks, personal communication) (Figure 4.10). It is difficult to estimate the productivity rates of large calanoid copepods because they were not identified to species. If it is assumed the standing stock of large calanoid copepods remains fixed for 10 days, pink salmon could consume about 19% of the available copepods. The average daily consumption of cladocerans and larvaceans for these years ranged from 0.40 - 1.68 x 10^{-4} gC/m^2 and 0.33 - 1.39 x 10^{-4} g C/m^2, respectively (Figure 4.10). These estimates of consumption only represent 0.13 - 0.57% and 0.01 - 0.06% of the cladocerans and larvaceans available (L. Haldorson, University of Alaska Fairbanks, personal communication). If the standing stocks of cladocerans and larvaceans were fixed over a ten day period, pink salmon could consume up to 5.7% of the cladocerans and up to 0.58% of the larvaceans.

The consumption estimates suggest that juvenile pink salmon were not limited by secondary production in PWS, but that they could potentially consume a significant amount of the large calanoid copepod standing stock. These estimates, however, assume that both the salmon and their prey are evenly distributed in PWS. The zooplankton samples taken in PWS were integrated from 60 m depth to the surface and collected at night, whereas, the pink salmon were collected in the day. It is likely that not all zooplankton were available to the juvenile pink salmon, since they are thought to occupy surface waters. Water column structure may also determine the availability of zooplankton to pink salmon. In areas of strong stratification, zooplankton may be concentrated in the upper layer and, therefore, be available to pink salmon. In areas of weak stratification, zooplankton may be more evenly distributed in the water column and, hence, less available to pink salmon juveniles.

It was found that pink salmon condition was lower in PWS than the adjacent GOA shelf in July, 1998, suggesting that growth conditions in PWS were poorer (Chapter 1). Paul (1997) suggests energy values less than 4-5 kJ/g wet weight are an indication of food limitation. The energy content of pink salmon varied among areas in PWS and in some cases was less than 4-5 kJ/g wet weight, indicating that there may be areas of limited food availability (Chapter 3, Paul 1997). It was also found that pink salmon condition and diet varied geographically in PWS, indicating that physical and biological processes occurring on local scales may be important determinants of fish growth

(Chapters 1 and 2). To determine if pink salmon have reached the carrying capacity of PWS, it would be important to account for the local differences that occur in PWS. It would also be important to examine the presence of other planktivores, such as sand lance, herring, and juvenile walleye pollock, that have similar habitats and prey as pink salmon. Fish planktivory, zooplankton availability, and water column structure may result in food limitation in local bays reducing the growth and survival of pink salmon resulting in poor fish condition and low energy content (Cooney et al. 1981; Paul 1997).

Summary

In PWS, bioenergetic model consumption estimates by juvenile pink salmon represent a small proportion of the available secondary production, 0.06-4.5%, but possibly a significant proportion of large calanoid copepod standing stock. Cooney (1993) estimated that zooplankton in PWS were not severely impacted by pink salmon consumption. These estimates of consumption in PWS assume that the primary and secondary production and pink salmon are distributed evenly throughout PWS and the period modeled. Low and geographically variable pink salmon energy content in PWS, however, indicate that local processes may be important in determining pink salmon growth. Water column stability and planktivory may play a critical role in determining zooplankton availability to juvenile pink salmon.

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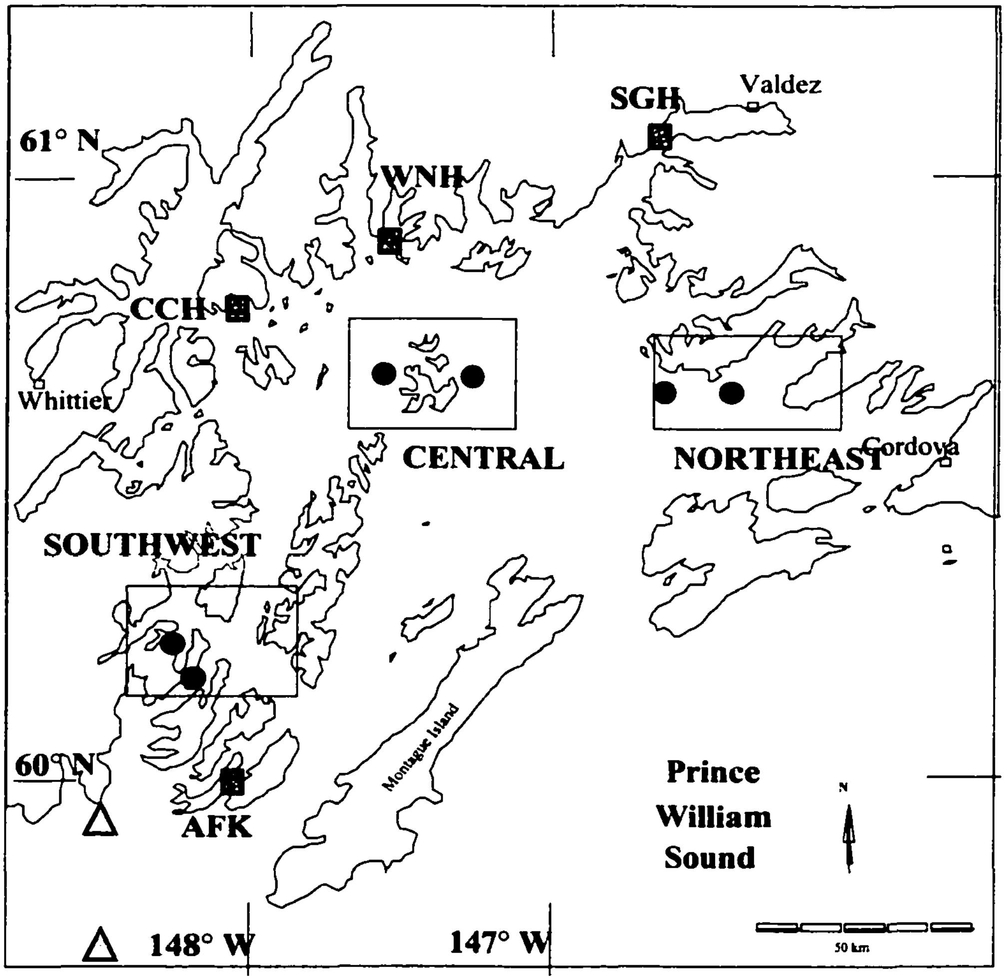

Figure 4.1. Study area in Prince William Sound, Alaska. The three study areas in PWS are represented by the large open boxes. The six stations sampled in July, 1998 are denoted by circles. The two stations sampled off of Cape Puget are denoted by triangles. The four pink salmon hatcheries in PWS are denoted by the small squares. CCH = Cannery Creek Hatchery, WNH = Wally Noerenberg Hatchery, SGH = Solomon Gulch Hatchery, AFK = Armin Koernig Hatchery.

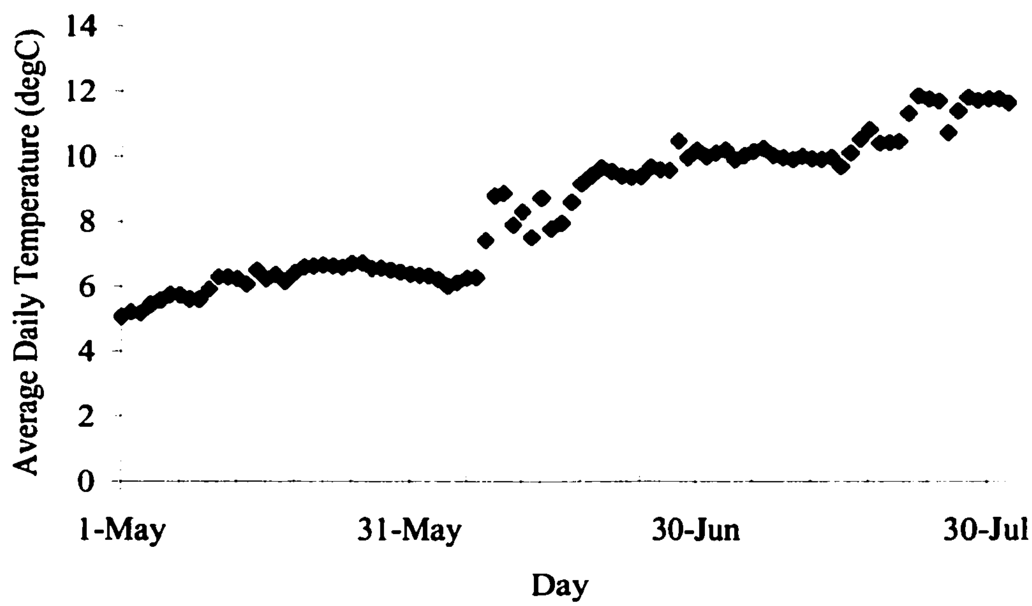

Figure 4.2. Average daily temperatures at 20 m depth at station GAK 1 in the mouth of Resurrection Bay, N. GOA, from May 1 to August 1, 2000. This is mooring data provided by Weingartner (personal communication).

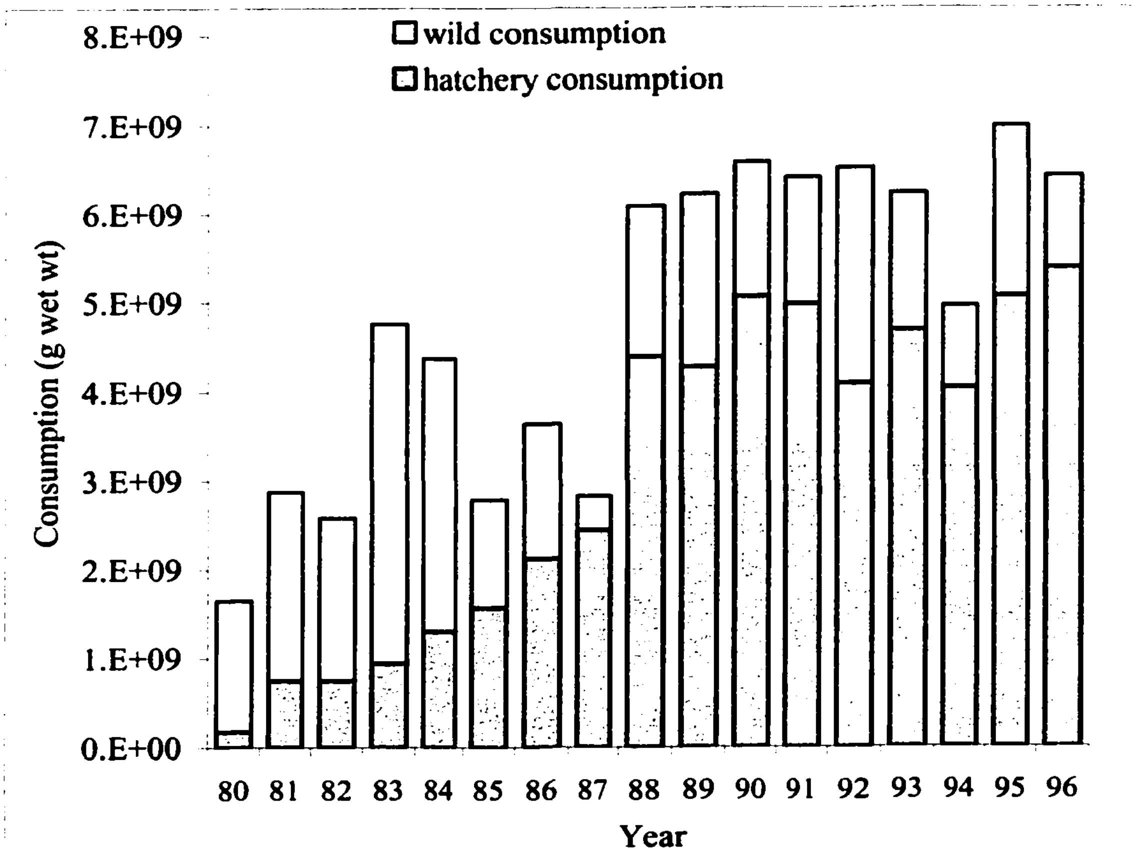

Figure 4.3. Total zooplankton consumption by juvenile pink salmon in PWS from 1980 to 1996. Consumption is expressed in grams of prey wet weight. Consumption is separated into the hatchery and wild fish components.

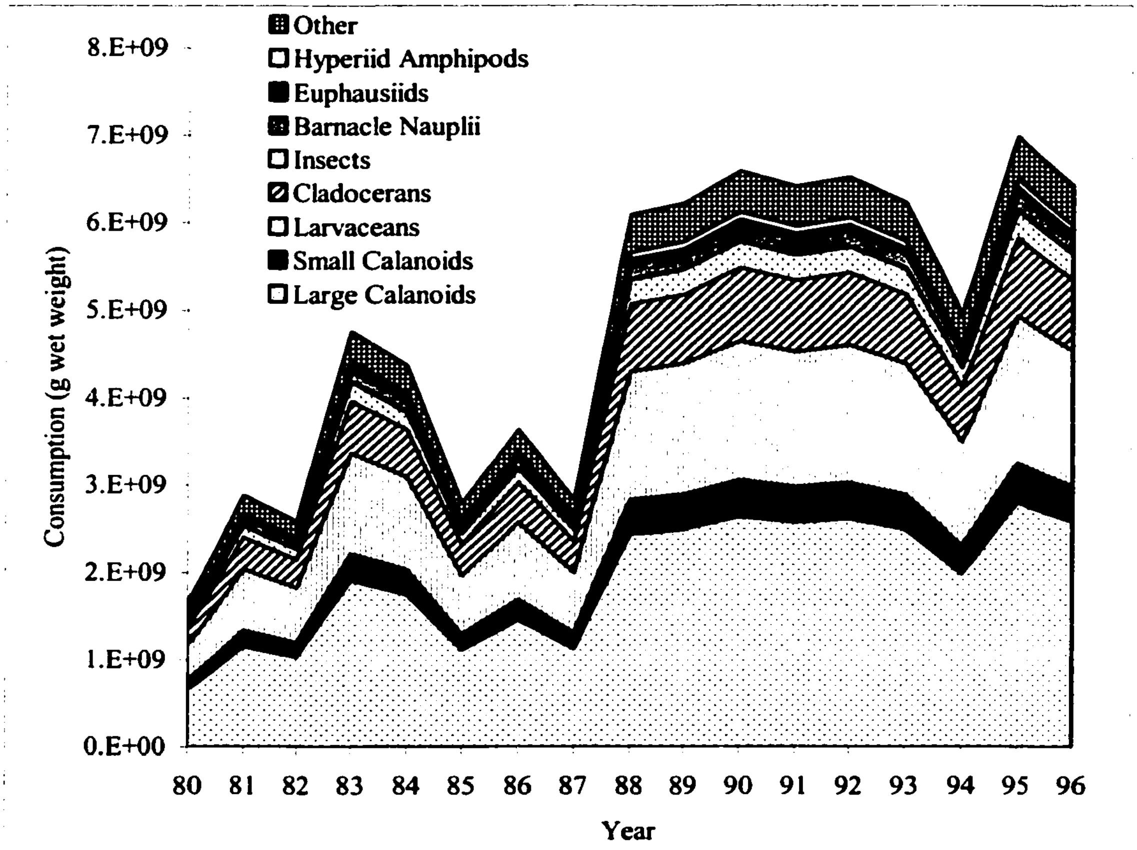

Figure 4.4. Consumption of zooplankton by juvenile pink salmon in PWS from 1980 to 1996. The eight main prey groups are shown, and all other prey groups were consolidated into the "other" category. The sum of all prey groups shown represents the total consumption of zooplankton by juvenile pink salmon. Consumption is expressed as grams of prey wet weight.

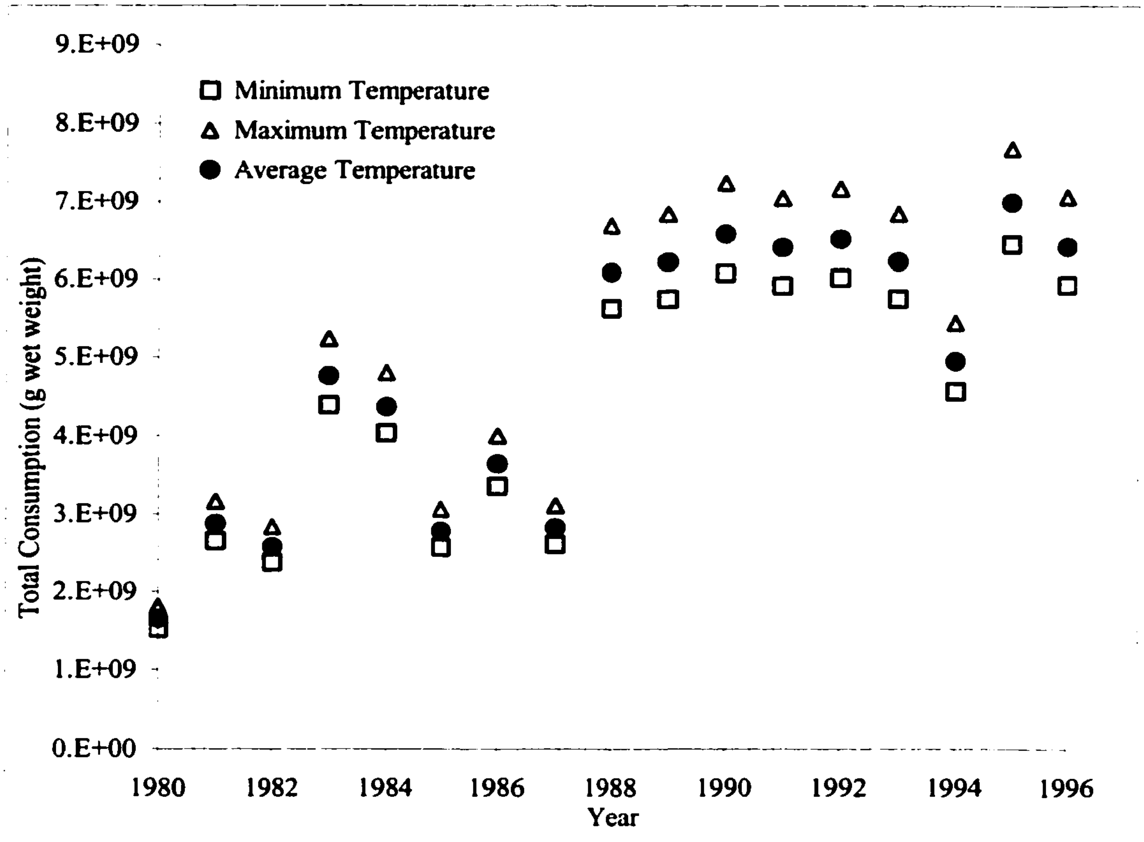

Figure 4.5. Pink salmon consumption estimates in PWS for 1980 to 1996. Consumption estimates for three different temperature regimes and for each year are shown. The black circle represents the temperature regime initially used in the model. The open squares and triangles above and below the black circle are the consumption estimates for the minimum and maximum temperature regimes utilized in the model. The "average" temperature regime was 6, 8, 10, 12 degrees C for days 1, 32, 62, 93 of the model. The minimum temperature regime was 4, 6, 8,10 degrees C for days 1, 32, 62, 93 of the model. The maximum temperatureregime was 8, 10, 12, 14 degrees C for days 1, 32, 62, 93 of the model.

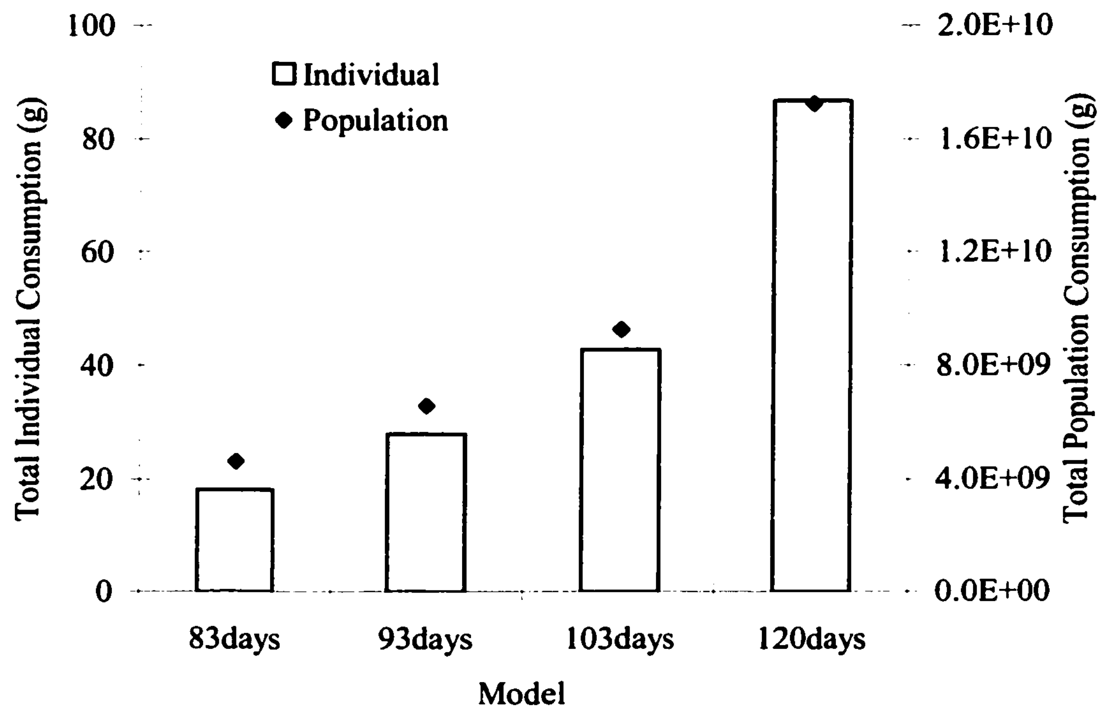

Figure 4.6. Individual and population consumption estimates for different time periods. The model was run for 83, 103, and 120 days assuming the same water temperature, diet, prey energy density, and predator energy density as for the original model day 93 (Table 4). A growth rate of 4% body weight per day was applied to the original fish weight (0.26 g), resulting in final weights of 6.48, 14.20, and 27.67g for days 83, 103, and 120, respectively. The mortality rate for the first 40 days modeled was 66%, as in the 93 day model. The same mortality rate after day 40 was applied to the different time periods, resulting in mortality estimates of 22.34, 31.14, and 37.84 for days 83, 103, and 120, respectively.

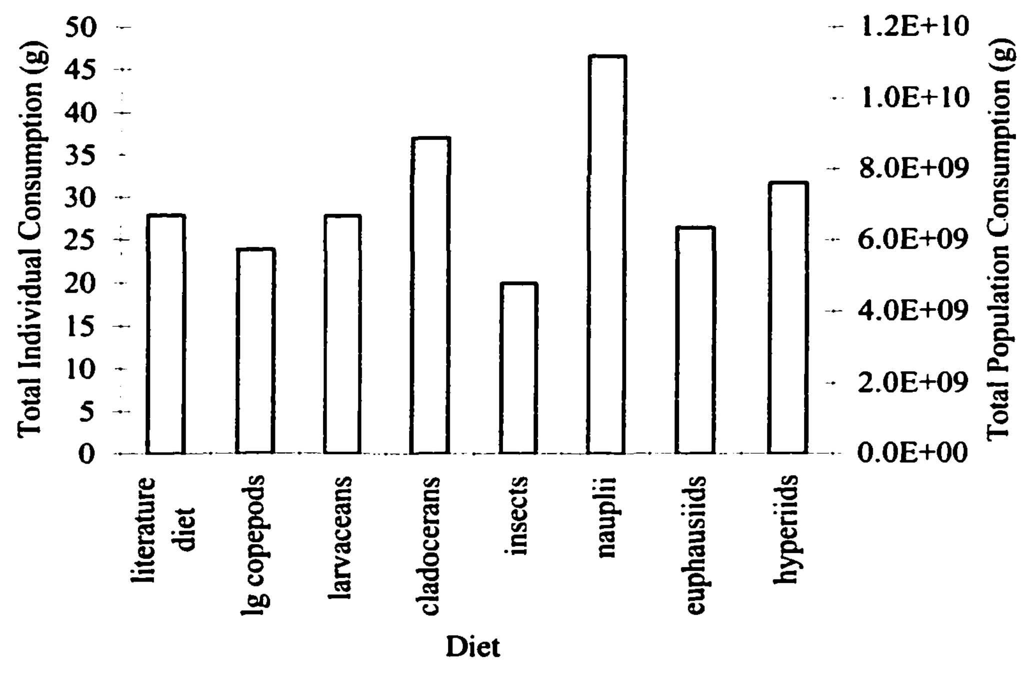

Figure 4.7. Individual and population consumption estimates for varying pink salmon diets. Individual and total consumption estimates are both represented by the bars. The literature diet refers to the diet utilized in the first model (Table 4). Diet was varied by restricting diets of pink salmon to one prey item, such as large copepods, larvaceans, cladocerans, insects, nauplii, euphausiids, or hyperiid amphipods.

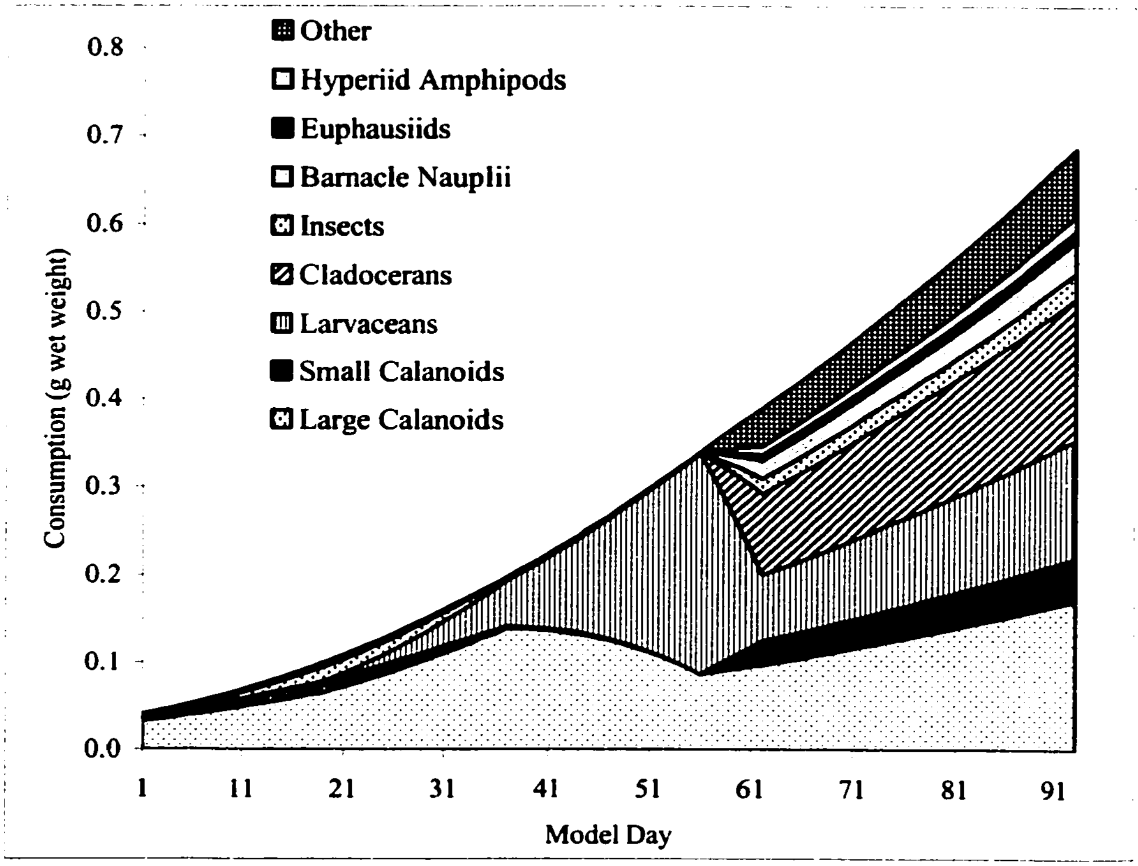

Figure 4.8. Consumption of zooplankton by an individual juvenile pink salmon in PWS over the 90 day period modeled for a typical year (1990). The eight main prey groups are shown and all other prey groups were consolidated into the "other" category. The sum of all prey groups shown represents the total consumption of zooplankton by an individual fish. Consumption is expressed as grams of prey wet weight.

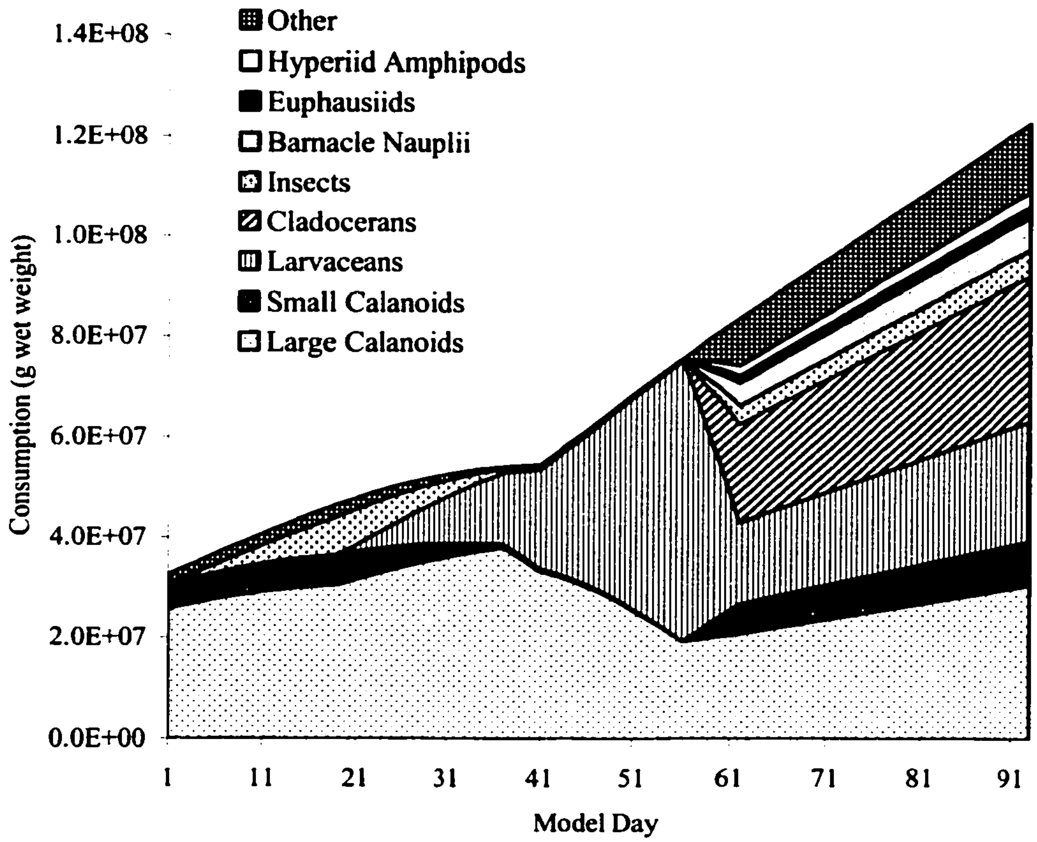

Figure 4.9. Consumption of zooplankton by a cohort of juvenile pink salmon in PWS over the 90 day period modeled for a typical year (1990). The eight main prey groups are shown and all other prey groups were consolidated into the "other" category. The sum of all prey groups shown represents the total consumption of zooplankton by a cohort of fish. Consumption is expressed as grams of prey wet weight.

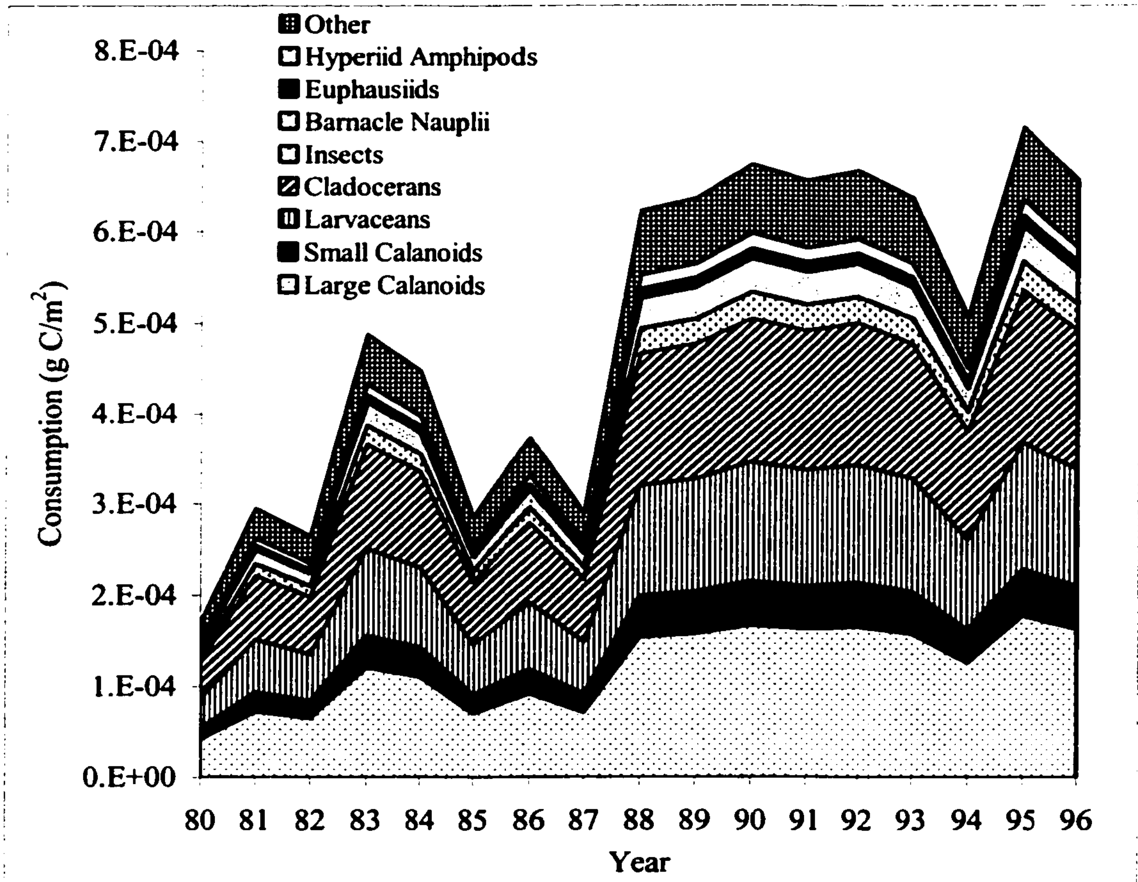

Figure 4.10. Average daily consumption of six zooplankton prey groups and total zooplankton by juvenile pink salmon in PWS from July 14-20, 1980 to 1996. Consumption is expressed as grams of carbon consumed per meter squared, assuming 1 g wet weight is equivalent to 0.057 g carbon, and assuming that PWS is 8.8 x 10^9 m^2.

Table 4.1. Sea surface temperatures utilized in the model from May to August.

Month	Model day	Temperature (deg. C)	Minimum temperature regime (deg.C)	Maximum temperature regime (deg.C)
May	1	6	4	8
June	32	8	6	10
July	62	10	8	12
August	93	12	10	14

Table 4.2. Sea surface temperatures measured with a CTD instrument on four occasions in 1994. Temperatures were measured at station GAK 1 in the mouth of Resurrection Bay, N. GOA.

Month	Sea surface temperature at GAK1, 1994 (deg. C)
May 2	5.346
May 24	7.726
June 26	11.54
August 1	13.06

Table 4.3. Pink salmon numbers in PWS from 1980-1996. The number of wild fry entering PWS was estimated using the hatchery fish survival.

Year of release	Total fry released [a, b, d]	# Hatchery returns [c]	# Wild returns [c]	Hatchery fish survival	#Wild fry	Wild and hatchery fry
1980	2.19E+07	2.41E+06	1.96E+07	0.110	1.78E+08	2.00E+08
1981	9.11E+07	5.93E+06	1.68E+07	0.065	2.58E+08	3.49E+08
1982	9.15E+07	4.78E+06	1.16E+07	0.052	2.21E+08	3.13E+08
1983	1.15E+08	5.27E+06	2.12E+07	0.046	4.62E+08	5.77E+08
1984	1.58E+08	8.49E+06	1.99E+07	0.054	3.71E+08	5.30E+08
1985	1.91E+08	7.27E+06	5.56E+06	0.038	1.46E+08	3.38E+08
1986	2.58E+08	1.84E+07	1.31E+07	0.071	1.83E+08	4.41E+08
1987	2.97E+08	1.13E+07	1.77E+06	0.038	4.64E+07	3.43E+08
1988	5.33E+08	1.72E+07	6.61E+06	0.032	2.05E+08	7.37E+08
1989	5.19E+08	3.18E+07	1.44E+07	0.061	2.35E+08	7.53E+08
1990	6.13E+08	3.10E+07	9.30E+06	0.051	1.84E+08	7.97E+08
1991	6.04E+08	7.76E+06	2.22E+06	0.013	1.73E+08	7.76E+08
1992	4.95E+08	4.85E+06	2.88E+06	0.010	2.94E+08	7.90E+08
1993	5.68E+08	2.99E+07	9.84E+06	0.053	1.87E+08	7.54E+08
1994	4.89E+08	1.50E+07	3.40E+06	0.031	1.11E+08	6.00E+08
1995	6.13E+08	2.08E+07	7.93E+06	0.034	2.33E+08	8.47E+08
1996	6.52E+08	2.37E+07	4.60E+06	0.036	1.26E+08	7.78E+08

a.) data from PWSAC web page (Dave Reggiani and Jeff Milton, personal communication)
b.) data from Olsen, 1994
c.) data from Tim Joyce (personal communication)
d.) data from Willette (personal communication)

Table 4.4. The different mortality rates utilized for calculating the number of wild pink salmon fry entering PWS. Hatchery survival rates were used for wild pink salmon in the original bioenergetics model run. Survival rates were varied by plus or minus 10% to get a range of wild fry numbers entering PWS. This was done for the 1995 year class of pink salmon.

Year	Hatchery fry	Hatchery returns	Proportion of hatchery survival	Wild returns
1995	613,151,120	20,849,647	0.0340	7,934,960

	Wild Survival	Wild fry	Total fry
same as hatchery fish =	0.0340	233,353,093	846,504,213
10% higher than hatchery fish =	0.0374	212,139,175	825,290,295
10% lower than hatchery fish =	0.0306	259,281,214	872,432,334

Table 4.5. Average fork lengths, wet weights, and energy content of juvenile pink salmon sampled at three time periods in 1998.

Sample date	Sample area		Fork length (mm)	Wet weight (g)	Energy content (J/g wet weight)
May 1998	PWS Hatcheries	Average	34.48	0.289	4,102
		n	150	150	50
		s.e.	0.28	0.011	61
July 1998	PWS	Average	91.55	8.038	3,883
		n	150	147	60
		s.e.	1.03	0.268	21
August 1998	Cape Puget, GOA	Average	129.63	19.286	4,359
		n	100	172	44
		s.e.	1.48	0.581	19

Table 4.6. The proportions (based on percent weight), caloric content, and percent indigestible prey items of juvenile pink salmon. (a.) Cooney et al. 1978; (b.) Laboratory derived values

	Diet proportions						Percent indigestible	Energy content (J/g wet weight)	Literature sources for energy content values
Source for diet proportions	(a.)	(a.)	(a.)	(a.)	(b.)	(b.)			
Model day	1	19	37	56	62	93	all days	all days	
Month	May 1	May 19	June 6	June 25	July1	Aug. 1	all	all	
Large calanoid copepods (>2.5mm)	0.792	0.656	0.703	0.256	0.249	0.249	9.04	3,810.7	Davis et al. 1998, Harris 1985, Kosobokova 1980
Small calanoid copepods (<2.5mm)	0.147	0.128	0.012	0	0.071	0.071	9.04	3,810.7	assume the same for large calanoid copepods
Harpacticoid copepods	0.046	0.048	0.006	0	0	0	9.04	3,810.7	assume the same for large calanoid copepods
Hyperiid amphipods	0	0	0	0	0.024	0.024	12.99	2,906.0	Davis et al. 1998, Harris 1985, Cooney et al. 1981
Euphausiids	0.004	0	0.001	0	0.016	0.016	10.35	3,454.8	Davis et al. 1998, Harris 1983
Insects	0	0.164	0.014	0	0.043	0.043	10.00	4,531.8	Griffiths 1977
Cladocerans	0	0	0	0	0.235	0.235	10.00	2,513.5	Cummins and Wuychek 1971
Larvaceans	0	0	0.264	0.739	0.195	0.195	10.00	3,287.8	Healey 1991, Cooney et al. 1981
Gastropods	0	0	0	0.004	0.011	0.011	8.50	2,619.8	Davis et al. 1998
Fish	0	0	0	0	0.011	0.011	8.98	5,353.4	Davis et al. 1998, Cianelli et al. 1998
Crab megalopae	0	0	0	0	0.006	0.006	10.00	3,795.7	Dawirs et al. 1986 (at 9deg.C assuming 30% dry weight)
Crab zoea	0.011	0.004	0	0	0.003	0.003	10.00	3,785.0	Dawirs et al. 1986 (at 9 deg. C assuming 30% dry weight)
Barnacle nauplii	0	0	0	0	0.055	0.055	10.00	2,045.3	Thayer et al. 1973
Barnacle cyprids	0	0	0	0	0.027	0.027	10.00	2,045.3	Thayer et al. 1973
Bivalve	0	0	0	0	0.001	0.001	10.00	1,787.4	Norrbin and Bamstedt 1984 (assume 10% dry weight as for pelecypoda), Thayer et al. 1973
Ostracod	0	0	0	0	0.002	0.002	10.00	2,585.7	Norrbin and Bamstedt 1984 (assume 10% dry weight)
Other	0	0	0	0.001	0.051	0.051	10.00	2,595.0	average value

Table 4.7. Prey weights and sources used in the diet analysis and modeling exercise. Polychaetes, polychaete larvae, invertebrate eggs, and unidentified crustaceans comprised less than 5% of pink salmon diets; therefore, they were consolidated into the "other" category.

	Prey item	Wet weight (mg)	Source
	Large calanoid copepod (>2.5mm)	0.170-1.173	laboratory
	Small calanoid copepods (<2.5mm)	0.030	Coyle personal communication
	Hyperiid amphipod	0.391	laboratory
	Euphausiids (young)	58.322	laboratory
	Insect	5.598	laboratory
	Cladoceran	0.070	laboratory
	Larvacean	1.487	Coyle personal communication
	Gastropod	0.038	laboratory
	Fish	10.748	laboratory
	Crab megalops	7.378	laboratory
	Crab zoeae	0.050	Cooney et al. 1981 (assume 80% water)
	Barnacle nauplii	0.169	Coyle personal communication
	Barnacle cyprid	0.219	Coyle personal communication
	Bivalve	0.001	Coyle personal communication
	Ostracod	1.428	Coyle personal communication
Other	Polychaete	22.000	Coyle personal communication
Other	Polychaete larvae	0.038	laboratory
Other	Invertebrate egg	0.010	Coyle personal communication
Other	Unidentified crustacean	1.690	Coyle personal communication

Table 4.8. Total consumption by juvenile pink salmon in PWS from 1980-96. Consumption is expressed as grams of wet weight for all fish, wild fish, and hatchery fish. Consumption is also expressed as grams of Carbon per meter squared, assuming 1 g wet weight is equivalent to 0.057 g Carbon and assuming that PWS is 8.8 x $10^9 m^2$.

Year	Total consumption g wet wt	Wild fish consumption g wet wt	Hatchery fish consumption g wet wt	Total consumption g C/m^2
80	1.65E+09	1.47E+09	1.81E+08	0.011
81	2.88E+09	2.13E+09	7.52E+08	0.019
82	2.58E+09	1.83E+09	7.55E+08	0.017
83	4.76E+09	3.82E+09	9.49E+08	0.031
84	4.37E+09	3.07E+09	1.31E+09	0.028
85	2.79E+09	1.21E+09	1.58E+09	0.018
86	3.64E+09	1.51E+09	2.13E+09	0.024
87	2.83E+09	3.83E+08	2.45E+09	0.018
88	6.09E+09	1.69E+09	4.40E+09	0.039
89	6.22E+09	1.94E+09	4.28E+09	0.040
90	6.58E+09	1.52E+09	5.06E+09	0.043
91	6.41E+09	1.43E+09	4.98E+09	0.042
92	6.52E+09	2.43E+09	4.09E+09	0.042
93	6.23E+09	1.54E+09	4.68E+09	0.040
94	4.95E+09	9.15E+08	4.04E+09	0.032
95	6.99E+09	1.93E+09	5.06E+09	0.045
96	6.42E+09	1.04E+09	5.38E+09	0.042

Table 4.9. Consumption by hatchery and wild pink salmon in PWS in 1995. Wild salmon survival rates were altered by plus or minus 10%, resulting in consumption estimates that varied by plus or minus 3%. Consumption by wild pink salmon represents about 30% of the total consumption.

Hatchery survival	Wild survival	Total consumption (g)	% Wild consumption	% change in wild consumption
0.0340	0.0340	6,987,789,347	27.57%	
0.0340	0.0374	6,812,671,069	25.70%	3%
0.0340	0.0306	7,201,821,676	29.72%	-3%

Table 4.10. Juvenile pink salmon consumption estimates in PWS in 1995. Pink salmon mortality rates were varied by plus or minus 10% resulting in a 21% change in the consumption estimates.

	Mortality				
	Day1-40	Day 41-93		Total consumption (g)	%Change
Original mortality	69	26.87	(0.6%/day)	6,987,788,784	
High mortality	75.9	29.131	(0.66%/day)	5,520,212,132	-21.00%
Low mortality	62.1	24.54	(0.54%/day)	8,481,355,684	21.37%

APPENDIX A-4.1

Model equations and notation as written in the Fish Bioenergetics 3.0 for Windows manual (Hanson et al. 1997).

The basic formula is:

$$C = (R + A + S) + (F + U) + (\Delta B + G)$$

ΔB = somatic growth

The formulae for consumption are:

$$\begin{aligned}
&C = C_{\max} \cdot p \cdot f(T) \\
&C_{\max} = CA \cdot W^{CB} \\
&f(T) = K_A \cdot K_B \\
&K_A = (CK1 \cdot L1)/(1 + CK1 \cdot (L1 - 1)) \\
&L1 = e^{(G1 \cdot (T - CQ))} \\
&G1 = (1/CTO - CQ)) \cdot \ln((0.98 \cdot (1 - CK1))/(CK1 \cdot 0.02)) \\
&K_B - (CK4 \cdot L2)/(1 + CK4 \cdot (L2 - 1)) \\
&L2 = e^{(G2 \cdot (CTL - T))} \\
&G2 = (1/(CTL - CTM)) \cdot \ln((0.98 \cdot (1 - CK4))/(CK4 \cdot 0.02))
\end{aligned}$$

The formulae for respiration are:

$$\begin{aligned}
&R = RA \cdot W^{RB} \cdot f(T) \cdot ACTIVITY \\
&S = SDA \cdot (C - F) \\
&f(T) = e^{(RQ \cdot T)} \\
&ACTIVITY = e^{(RTO \cdot VEL)} \\
&VEL = Act \cdot W^{RK4} \cdot e^{(BACT \cdot T)}, \\
&\textit{when} \\
&T \leq RTL
\end{aligned}$$

APPENDIX A-4.1 continued

The formulae for egestion and excretion are:

$$F = PF \cdot C$$

$$U = UA \cdot T^{UB} \cdot e^{(UG \cdot p)} \cdot (C - F)$$

$$PF = ((PE - 0.1)/0.9) \cdot (1 - PFF) + PFF$$

$$PE = FA \cdot T^{FB} \cdot e^{FG \cdot p}$$

$$PFF = \sum (PREY[n] \cdot DIET[n])$$

Table A-4.2. Values of parameters used in the bioenergetics model. The notation, definitions, and values are presented as in the Fish Bioenergetics 3.0 for Windows manual (Hanson et al. 1997).

Symbol	Definition	Value
	CONSUMPTION	
C	specific consumption rate (g/g/d)	
Cmax	maximum specific feeding rate (g/g/d)	
p	proportion of maximum consumption	
f(T)	temperature dependence function	
T	water temperature (degree C)	
W	fish weight (g)	
CA	intercept of the allometric mass function	0.303
CB	slope of the allometric mass function	-0.275
CQ	temperature corresponding to a small fraction of maximum consumption rate	3
CTO	temperature corresponding to 0.98 of maximum consumption rate	20
CTM	temperature (>CTO) corresponding to 0.98 of maximum consumption rate	20
CTL	temperature corresponding to a reduced fraction of maximum consumption rate	24
CK1	proportion of maximum consumption at CQ	0.58
CK4	proportion of maximum consumption at CTL	0.5
	RESPIRATION	
R	specific rate of respiration (g/g/d)	
RA	intercept of the allometric mass function (g/g/d)	0.00143
RB	slope of the allometric mass function	-0.209
RQ	approximation of Q10	0.086
RTO	coefficient of R as a function of swimming speed	0.0234
RTL	temperature, above which activity relationship changes	25
RK4	coefficient of swimming speed as a function of weight	0.13
ACT	activity multiplier (intercept cm/s)	9.9
BACT	coefficient of swimming speed as a function of temperature	0.0405
S	proportion of assimilated energy lost to specific dynamic action	
SDA	specific dynamic action	0.172
	EGESTION/EXCRETION	
F	specific egestion rate (g/g/d)	
FA	intercept of proportion egested as a function of temperature and ration	0.212
FB	coefficient of water temperature dependence of egestion	-0.222
FG	coefficient of p-value as a function of egestion	0.631
UA	intercept of proportion excreted as a function of temperature and ration	0.0314
UB	coefficient of water temperature dependence of excretion	0.58
UG	coefficient of p-value as a function of excretion	-0.299
PREY[n]	proportion of indigestible nth prey	
DIET[n]	proportion of nth prey in diet	

Table A-4.3. Average daily temperatures at 20 m depth at station GAK1 (in the mouth of Resurrection Bay, N.GOA) from May 1 to August 1, 2000. This data was used in the bioenergetics model for the 1995 year class to examine daily temperature variation on the overall fish consumption. This mooring data was provided by Weingartner (personal communication).

Date	Average temp. (deg.C)	Date	Average temp. (deg.C)	Date	Average temp. (deg.C)	Date	Average temp. (deg.C)
1-May	5.083	30-May	6.430	28-Jun	10.468	27-Jul	11.390
2-May	5.230	31-May	6.375	29-Jun	9.943	28-Jul	11.818
3-May	5.190	1-Jun	6.333	30-Jun	10.193	29-Jul	11.715
4-May	5.453	2-Jun	6.318	1-Jul	9.983	30-Jul	11.758
5-May	5.580	3-Jun	6.218	2-Jul	10.095	31-Jul	11.760
6-May	5.763	4-Jun	6.008	3-Jul	10.180	1-Aug	11.640
7-May	5.750	5-Jun	6.115	4-Jul	9.885		
8-May	5.610	6-Jun	6.255	5-Jul	10.015		
9-May	5.610	7-Jun	6.273	6-Jul	10.138		
10-May	5.925	8-Jun	7.413	7-Jul	10.233		
11-May	6.285	9-Jun	8.790	8-Jul	10.008		
12-May	6.293	10-Jun	8.860	9-Jul	9.938		
13-May	6.240	11-Jun	7.895	10-Jul	9.880		
14-May	6.060	12-Jun	8.310	11-Jul	9.998		
15-May	6.498	13-Jun	7.515	12-Jul	9.915		
16-May	6.230	14-Jun	8.723	13-Jul	9.898		
17-May	6.378	15-Jun	7.780	14-Jul	9.965		
18-May	6.140	16-Jun	7.955	15-Jul	9.673		
19-May	6.418	17-Jun	8.600	16-Jul	10.095		
20-May	6.593	18-Jun	9.158	17-Jul	10.508		
21-May	6.633	19-Jun	9.400	18-Jul	10.813		
22-May	6.660	20-Jun	9.643	19-Jul	10.395		
23-May	6.635	21-Jun	9.533	20-Jul	10.413		
24-May	6.603	22-Jun	9.380	21-Jul	10.445		
25-May	6.715	23-Jun	9.348	22-Jul	11.310		
26-May	6.728	24-Jun	9.363	23-Jul	11.858		
27-May	6.545	25-Jun	9.653	24-Jul	11.770		
28-May	6.565	26-Jun	9.578	25-Jul	11.703		
29-May	6.495	27-Jun	9.563	26-Jul	10.720		

General Summary

The main goal of this study was to advance the understanding of juvenile pink salmon ecology in PWS and the GOA. Previously, some understanding of the feeding conditions of PWS and the GOA were known; however, geographic and temporal variations in condition and diet, and hatchery versus wild fish condition were not well studied. The distribution, timing, and movement of juvenile pink salmon through PWS and the adjacent GOA shelf indicated pink salmon occupied PWS from their time of release or saltwater entry in May until mid-July (Chapter 1). Pink salmon then moved out of PWS into the Gulf of Alaska, and migrated westward along the shelf. PWS hatchery pink salmon were found up to 625km west of PWS in August, whereas, others were still found near PWS in October. This protracted migration of pink salmon from PWS may have been related to hatchery or spawning river location and/or varying growth conditions.

The period and area in the nearshore life history of juvenile pink salmon where growth or condition was enhanced was examined (Chapter 1). The energy content of pink salmon after release was highest in August on the GOA shelf and lowest in PWS. This was also observed for the cohorts of CCH and WNH fish sampled, indicating that growth conditions were better in August on the GOA shelf. The opportunity to sample the 1998 year class several times in their first months at sea revealed differences in condition between fish in PWS and the GOA, which had not been previously documented.

Fish lengths, weights, and condition varied among stations sampled within each time period examined. I estimated the growth rate of PWS hatchery pink salmon through the first three months of life at sea (Chapter 1). Growth rates ranged from 3.63-6.66% body weight/per day depending upon release date and location where fish were recaptured. These are comparable to previously observed growth rates for juvenile pink salmon. Differences in fish weights, condition, and growth rates could be due to variations in feeding conditions among the wide variety of areas and times sampled.

Pink salmon tended to consume increasingly large prey items through the course of their first six months at sea (Chapter 2). Bivalves, small and large copepods, gastropods, cladocerans, larvaceans, and barnacle nauplii were important prey items in July in PWS and the GOA. In August, the smaller prey items, such as bivalves, small copepods, cladocerans, and barnacle nauplii were not consumed. In October, pink salmon were consuming primarily large prey, such as large copepods, large hyperiid amphipods, crab megalopae, fish, a large pteropod (*Clio* sp.), and euphuasiids.

Pink salmon consumed prey items that were not sampled with plankton nets, indicating that zooplankton was not sampled effectively and/or that fish were utilizing different or smaller-scale patches of zooplankton (Chapter 2). Zooplankton was sampled at stations 10-100km apart. If zooplankton patches were smaller than this, as suggested by Mackas et al. (1980), then zooplankton consumed by fish may not have been sampled. The zooplankton was sampled over the upper 20 and 60m of the water column; however, juvenile pink salmon are thought to occupy only surface waters (Moulton 1997, Godin 1981). Also, plankton and fish sample collections were sometimes separated by up to two days. Any of these characteristics of zooplankton sampling could be the cause of disparities between fish stomach contents and zooplankton samples. Future zooplankton sampling needs to occur at the same time and location as fish sampling. Zooplankton samples should be taken from surface waters that juvenile pink salmon occupy. The GLOBEC project has already altered their sampling so that surface (upper 1m) zooplankton is sampled at the same time and location of all fish samples. Three replicates are taken to enable some estimate of variability. Additionally, temperature, salinity, and fluorescence are being measured in the upper 100m of the water column concurrent with fish and zooplankton sampling.

Fish condition in PWS varied geographically; however there were no significant differences among hatchery groups and/or wild pink salmon at any one location in PWS (Chapter 3). The similarity of fish condition at a single location indicates that fish were not mixing extensively throughout PWS and that those fish had been together for some time. The variation in fish condition among areas of PWS indicates that growth conditions also varied geographically.

Geographic variation in fish condition, diet, and zooplankton densities suggest that local processes and/or food depletion are important determinants of juvenile pink salmon growth. Varying zooplankton availability may be related to geographic variation in water column stability, proposed as the optimal stability hypothesis by Gargett (1997). Increased freshwater input in the North GOA increases the water column stability, retaining phytoplankton in the euphotic zone (Gargett 1997). Primary and, therefore, secondary production may then increase, benefiting juvenile pink salmon growth. On a smaller scale, water column stability varied among stations where fish were sampled in PWS in 1998, possibly resulting in the observed variation in zooplankton abundance (Haldorson, pers. comm.). In areas where the water column was more stable, the zooplankton density was higher and the fish were in better condition. In areas where the water column is not stable and zooplankton density is low, planktivory by fish may further reduce feeding conditions for juvenile pink salmon. If small-scale processes are important determinants of fish feeding and condition, there may be localized depletion of food resources in some areas of PWS (Cooney et al. 1978, Paul 1997). The results of this study are consistent with the optimal stability hypothesis as a process of regulation of pink salmon growth and condition.

Data indicate that small scale processes may be important in determining pink salmon condition and survival; therefore, the samples collected opportunistically in this study may not represent the entire pink salmon population of the North Gulf of Alaska. A more synoptic survey would be needed to arrive at general results that would apply to all pink salmon populations in the Gulf of Alaska and/or other areas. It is difficult to design a project that is broad enough to examine all pink salmon in PWS and the GOA, but detailed enough to examine local processes that are apparently important in determining pink salmon growth and condition. An example of a broad-scale survey is the Ocean Carrying Capacity (OCC) project, which is currently being conducted by the National Marine Fisheries Service in the GOA. The OCC project collects salmon samples along several transects throughout the GOA, and would, therefore, be able to describe the distribution of the GOA pink salmon populations and large scale processes that affect them. Broad-scale studies need to be accompanied by detailed small-scale studies, such as GLOBEC, to understand the local processes that can affect salmon. Process and monitoring studies are currently being conducted by the GLOBEC project and include four sampling periods each year in PWS and along the Seward hydrographic transect. This will improve our ability to understand local processes that affect PWS pink salmon, and these processes may be applicable to pink salmon in other systems. A combination of the OCC and GLOBEC projects will enable scientists to examine both large and small-scale processes that affect pink salmon in the N. GOA.

Consumption by pink salmon was estimated to represent a small fraction of the zooplankton production but potentially a large proportion of the standing stock available in PWS (Chapter 4). Consumption estimates assume that both salmon and zooplankton are evenly distributed in PWS and that productivity is fixed. To address issues of carrying capacity and interactions between hatchery and wild pink salmon, future research should concentrate on estimating primary and secondary production available to pink salmon. A more detailed examination on pink salmon prey use is also needed to determine if pink salmon are selective feeders, what portion of the zooplankton community they utilize, and to examine any diel patterns of prey use. Zooplankton density can be high in PWS, but the majority of it is composed of small calanoid copepods, which were not consumed by most fish in PWS (Chapter 2). The energetic value of prey items also needs to be investigated. The energy content of prey items as well as handling time and digestibility of prey items consumed by pink salmon is not well known. The water column structure and vertical distribution of both fish and plankton also needs to be examined to determine the availability of zooplankton to fish. Estimates of pink salmon density and a description of the areas they utilize are needed to enable scientists to understand if local food depletion is occurring. These studies should carried out over many years in order to observe the full range of variation in both pink salmon growth, diet, and survival, and environmental conditions.

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